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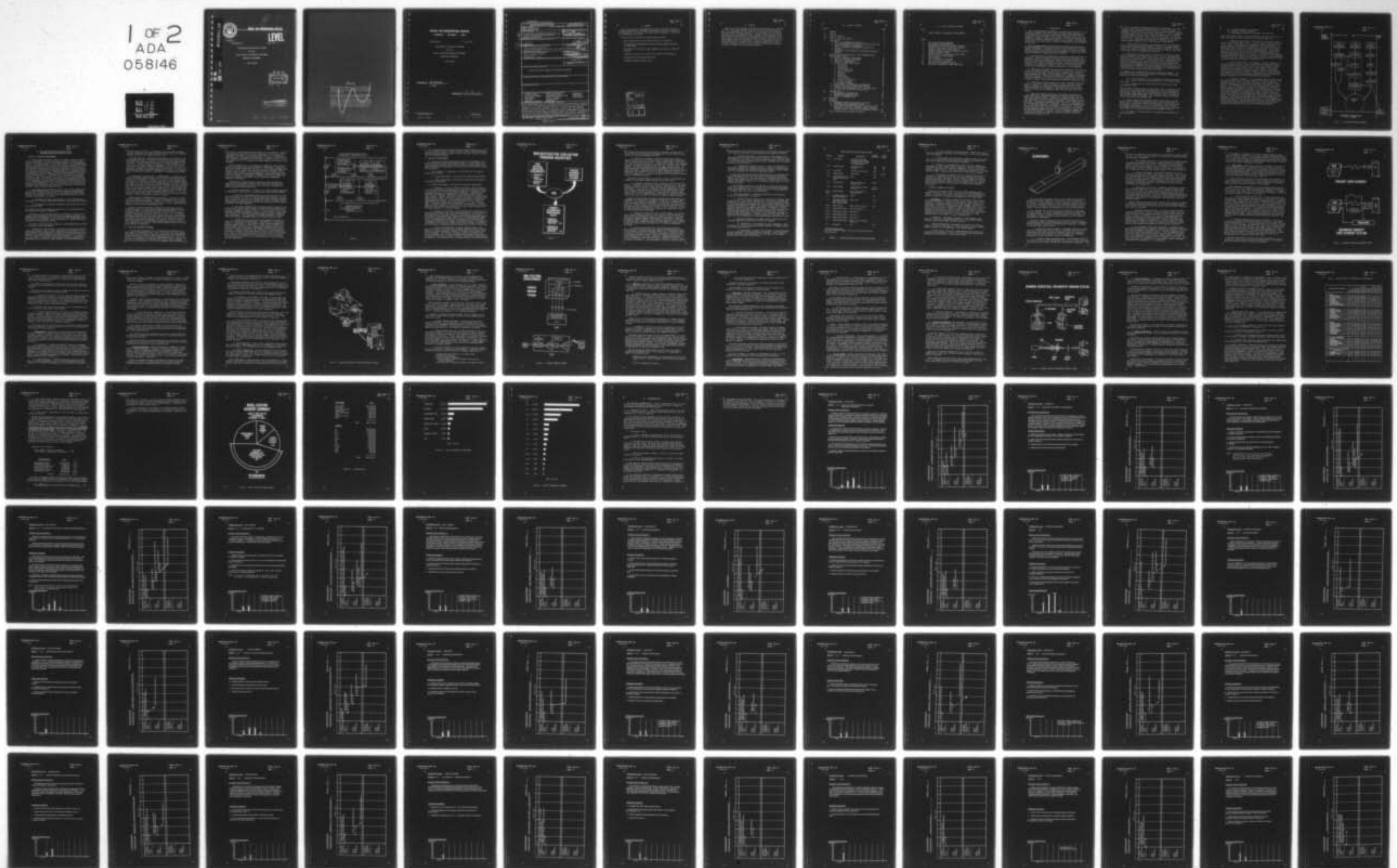

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5 JULY 1978

NON-DESTRUCTIVE EVALUATION SYSTEMS
FOR THE
NAVAL AVIATION MAINTENANCE ENVIRONMENT
TECHNOLOGY ASSESSMENT

FINAL REPORT

78 08 28 029

4ND-NAEC 5213/3 (Rev. 10-77)

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NAVAL AIR ENGINEERING CENTER

LAKEHURST, NEW JERSEY 08733

NAEC-GSED-120 5 JULY 1978

NON-DESTRUCTIVE EVALUATION SYSTEMS

FOR THE

NAVAL AVIATION MAINTENANCE ENVIRONMENT

TECHNOLOGY ASSESSMENT

FINAL REPORT

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Under NAVAIRSYSCOM direction, NAEC-GSED conducted an investigation and analysis of the field of non-destructive evaluation as it relates to the Naval aviation community. This report finalizes that task. Areas of discussion include: general description of what NDE is and why it is practiced, how inspection requirements are established and suggested methods for improvement, assessment of the positive impact expanded utilization of NDE could provide, discussion of present and future field inspection requirements, technology base assessment/projection, and recommended research program options.

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I. SUMMARY

Under the direction of NAVAIRSYSCOM (AIR-340E), NAEC-GSED conducted a one year planning task to investigate and analyze the field of non-destructive evaluation as it relates to the Naval aviation community. This report is a culmination of that task.

Specific areas of discussion contained herein include

- General description of what NDE is and why it is practiced.
- How inspection requirements are established and suggested methods for improvement.
- Assessment of the positive impact expanded utilization of NDE could provide.
- Discussion of present and future field inspection requirements.
- Technology base assessment/projections.
- Recommend research program options.

II. PREFACE

Application of Non-Destructive Evaluation has delivered, and continues to offer, considerable benefits within the aviation maintenance environment. The requirement for more effective utilization of this technology area has become increasingly apparent. Aircraft design trends utilizing more highly stressed components, the principles of fracture mechanics and the application of advanced structural materials such as graphite, boron epoxy composites have produced more capable military aircraft with new and often complex inspection requirements. These new requirements along with the prevailing need to improve current inspection capability to reduce in-service material failures as well as improve maintenance efficiencies provides the impetus for a vigorous NDE program.

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V. INTRODUCTION

A. WHAT IS NON-DESTRUCTIVE EVALUATION? Non-Destructive Evaluation is the systematic assessment of a part or material sample without imparing its future usefulness. Optimally non-destructive evaluation should bear an equivalency to physical "proof" tests without having to resort to any disassembly or component removal for inspection. The methods routinely used in the Naval Aviation environment include visual or optical, dye penetrant, magnetic particle, eddy current, ultrasonic, radiographic and spectrometric oil analysis.

B. WHY IS NON-DESTRUCTIVE EVALUATION PRACTICED WITHIN THE AVIATION MAINTENANCE ENVIRONMENT? The general impetus for practicing NDE is to improve safety of operations by minimizing in-service material failures and improving maintenance efficiencies by reducing disassembly to inspect operations. Specific categories of application are as follows:

1. Tracking in-service design deficiencies until modifications are incorporated. Because military aircraft are often the proving ground for advanced structural, aerodynamic and material application concepts, design deficiencies do surface occasionally. While it is impossible to instantaneously correct these situations, NDE offers, within the present state-of-the-art, the capability to predict - thus avoid - these in-service failures until appropriate airframe modifications can be incorporated.

2. Operational environment quality assurance mechanism. Navy aircraft, utilized for numerous missions, are subject to varying levels of stress. Factors ranging from higher than anticipated landing loads to flight envelop excursions and combat inflicted damage tend to degrade the aircraft's structural integrity. NDE within the maintenance environment allows this structural degradation to be qualified on an as required basis, in order to improve safety of operations and minimize unscheduled maintenance tasks.

3. Monitoring of airframe condition in order to optimize maintenance policies. The present trend of extending aircraft operational cycles makes it desirable to selectively induct airframes which are the most severely degraded for refurbishment. NDE allows these structural conditions to be evaluated and appropriate depot induction plans to be formulated.

4. Improve maintenance productivity by minimizing disassemble-to-inspect operations. Maintenance manhours per flight hour has, over the years, moved steadily upward. Significant contributing factors are aircraft maintenance actions which involve much airframe disassembly and, in many cases, trial and error component replacement. This situation creates two modes of unnecessary resource depletion. The first is the expenditure of maintenance manhours to disassemble, inspect, and reassemble, when more powerful NDE inspect only techniques could be applied. The second is the unwarranted burden placed on logistic resources to stock and refurbish components replaced by trial and error procedures, brought about via inadequate diagnostic capability. Air Force studies (Reference 1) indicate the potential for reducing scheduled maintenance by 22% and unscheduled maintenance by 17%.

C. WHY IS A TECHNOLOGY ASSESSMENT/APPLICATION PLAN REQUIRED? The technological domain of Non-Destructive Evaluation is large and dynamic. It integrates the disciplines of material science, structural design, physics, mechanical, electrical and human factors engineering in order to accomplish its stated goals. Because of this large technological span and numerous techniques embodied in the science of NDE, the field tends to be unwieldy and difficult to coordinate. This is further complicated by the fact that a host of users, those industries applying or developing improved NDE systems concern themselves with a broad spectrum of applications.

1. Despite these difficulties, the demand for improved and expanded NDE within the Naval Aviation environment continues to command attention. Fleet losses, caused by material defects primarily, along with the need to promote "on condition" maintenance practices whenever possible, rank high as profitable areas for expanded NDE capability.

2. Realizing, then, that there is a large body of potentially applicable technology and a recognized fleet need to fulfill, what approaches should be taken in order to gain the most from the often limited resources available for such ventures? It was recognized that a "Comprehensive Non-Destructive Evaluation Plan" was required which would systematically address new technology areas, define current and future requirements and provide specific recommendations for allocating available resources. This report provides a background technology assessment and provides specific recommendations as a first step toward development of a comprehensive NDE plan for the Naval Aviation Maintenance Environment.

D. DESCRIPTION OF NON-DESTRUCTIVE EVALUATION FUNCTIONAL ELEMENTS. The application of NDE to aircraft development and deployment phases occurs basically in three specific phases:

(1) quality assurance in the development and manufacturing phase
(2) flaw detection and system diagnostics in the aircraft deployment phase
(3) overhaul quality assurance employed during periodic depot refurbishment cycles.

This task deals primarily with the second phase, that of supporting flight operations at the intermediate and organizational levels of maintenance. This is not to imply that these other phases are of lesser importance or that meaningful improvements could not be realized within the manufacturing or depot overhaul environment. These functional areas are, however, outside the scope of this program task.

1. Figure 1 depicts the functional elements which support the "NDE System" at the intermediate and organizational levels of maintenance. At these levels, the practice of NDE is conducted with the most flexibility and breadth of application. It is also interesting to note that while considerable NDE related responsibility exists at these levels, the tasks are attempted with a minimum of personnel and equipment resources.

2. The support of the NDE System is accomplished by providing three specific elements:

(1) documented inspection requirements
(2) adequate inspection equipment
(3) knowledgeable personnel to implement the inspections.

These three elements share a series relationship, such that if any one element is missing, the chain is broken and the system breaks down.

a. Inspection Requirements. This aspect of NDE cannot be understated. The "nothing happens without a piece of paper" philosophy prevails in this aspect of the maintenance environment as well as many others. In order to promote an effective and comprehensive fleet NDE program, documented inspection requirements - either manuals, bulletins or maintenance requirement cards - have to be developed and promulgated. The difficulty lies in the fact that this function is usually delegated to maintenance engineering personnel which often times have a limited knowledge of the total NDE capability available. In order for this function to be adequately performed, maintenance policy functions need to maintain a working knowledge of NDE practices and a rapport with NDE research and development activities which provide new and more powerful inspection tools.

b. Inspection Equipment. This segment of the NDE "composite" is the most easily recognized. Years of evolutionary development have made available numerous "off-the-shelf" systems which exist because of demonstrated needs. Ultrasonic, eddy current, x-ray, magnetic particle and penetrant systems readily available for a large number of applications. In addition to commercially available systems, a number of prototype systems, applicable to peculiar inspection requirements, have been developed and an active research and development community continues to pursue promising innovations in the field of Non-Destructive Evaluation.

c. Inspection Personnel. If the equipment aspects of NDE are the most readily perceived, the personnel aspects of NDE are probably the least readily perceived. Within the flight operational support environment, automated NDE Systems are completely non-existent. This implies, however, because of the subjective nature of most non-automated NDE, that a large amount of operator judgement is required for conducting most inspections. While equipment developments have improved this situation, the inspection technician still plays a very significant role in the NDE process. Training, recent experience and motivation are probably the most significant factors which influence the performance and effectiveness of the NDE technician. This aspect of the NDE process has just recently begun to attract attention. Only a handful of programs have surveyed the performance of NDE technicians and the results were quite varied. It can be safely stated, however, that there is a significant difference between the maximum theoretical equipment sensitivity and the actual inspection sensitivity and reliability as performed in the field with operational personnel.

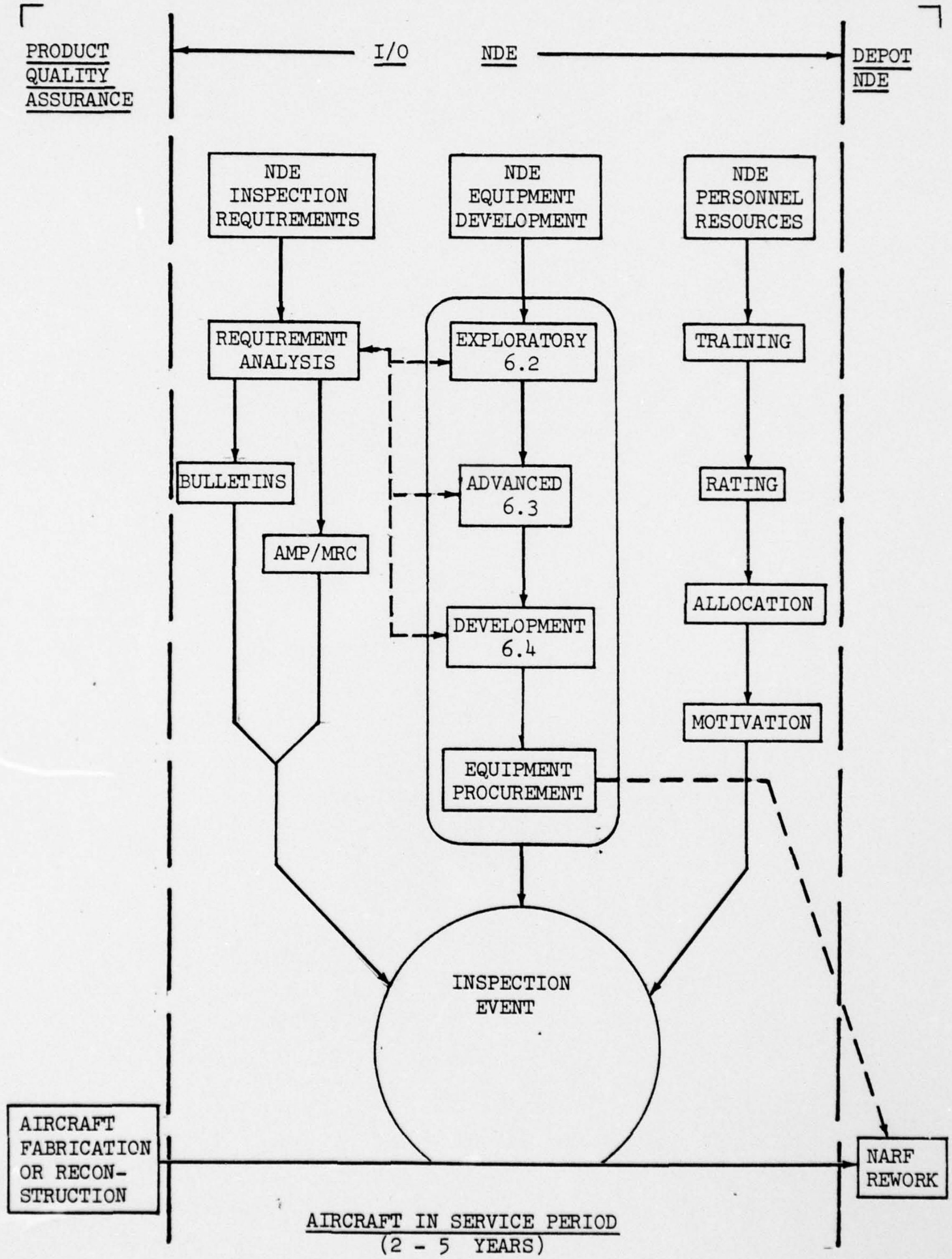


Figure 1. NDE SYSTEM FUNCTIONAL ELEMENTS

VI. NAVY NON-DESTRUCTIVE EVALUATION AT THE INTERMEDIATE AND ORGANIZATIONAL LEVELS

A. ORIGIN OF INSPECTION REQUIREMENTS.

1. Service Bulletin Process. There are a number of ways by which inspection requirements are established and promulgated. The most common route for in-service aircraft is the Safety Bulletin or UR (Unsatisfactory Report). The Cognizant Field Activity (CFA), usually the prime NARF (Naval Air Rework Facility), works up a particular inspection technique for aircraft material failures which occur and are determined to be non-isolated. These are then forwarded by the particular NARF to all operational activities employing similar aircraft. Compliance ranges from suggested practice to mandatory time interval repetitive inspections depending on the nature of the suspected defect. If a Bulletin is to be conducted at specified intervals, it may be incorporated in the next revision of the maintenance requirement cards. This option is also open to local maintenance activities to supplement their existing MRC (maintenance requirement card) decks. It is an unfortunate situation, but the MRC reflects only a portion of the documented NDE requirements. This is more prevalent in out-of-production aircraft as their MRC decks have longer revision intervals and they often experience higher inspection Bulletin traffic.

2. Undocumented/Localized NDE Practices. This is a very significant, yet relatively underdeveloped, area of NDE (Non-Destructive Evaluation) applications. During the course of day to day operations, NDE personnel develop a limited rapport with other local maintenance functions. Local practices are developed as a result of

a. maintenance personnel becoming aware of local NDE capability and applying it to improve either their efficiency and/or quality of work or

b. NDE personnel discovering maintenance deficiencies which could be alleviated by NDE.

The primary reason these informal exchanges are not fully appreciated is that they are not usually documented.

Occasionally, highly motivated personnel, discovering a material discrepancy, which they believe could exist in other similar aircraft, will forward written correspondence to the respective TYCOM recommending a fleet wide inspection be performed. Review and approval by cognizant NARF would then result in an inspection bulletin.

This aspect of the NDE mission should not be underestimated even though it is rather difficult to quantify.

3. Introduction of New Aircraft. The evolution of aircraft structural design utilizing more highly stressed components, the principles of fracture mechanics and the application of advanced structural materials such as graphite, boron, epoxy composites have produced more capable military aircraft with new and often complex inspection requirements. As a result of this trend, NDE is necessarily being considered during the formulation of maintenance policy for new air weapon systems. The design philosophy of

"fracture mechanics" which is being applied to new aircraft development programs increasingly, provides a relation between flaw size and expected remaining fatigue life or remaining service life.

The requirement for a systematic NDE program for new aircraft is now more apparent than ever. The Air Force has led the way in requiring NDI (Non-Destructive Inspection) manuals for all new aircraft weapon systems since 1966. The Navy presently has three (3) airframe NDI manuals, S-3A, A-7 and F-14, in various stages of development. The F-18 which is presently under development at McDonnell Douglas will be delivered with an NDI manual. However, just having a manual is not enough. To insure a comprehensive NDE program, inspection requirements will have to be incorporated in maintenance requirement cards (MRCs) to the maximum extent possible.

4. Maintenance Program Analysis. COMNAVAIRLANT, in defining its ten foremost maintenance problems said, "While difficult to describe non-destructive test techniques as a problem, it is an area which promises great dividends, in our opinion, if properly exploited. As the personnel crunch gets tighter, we find ourselves often generating many of our daily problems by taking things apart and putting them back together incorrectly. Greater use of NDT could avoid at least some of this. We don't see, from this distance, a very vigorous program to take advantage of all available NDT procedures and we think such a program is worth strong pursuit. We have much to do at this level utilizing that equipment already available, but a companion development effort should be structured to provide us with all means available, to avoid disassembly in order to inspect."

These comments by COMNAVAIRLANT are indicative of the trend in modern aircraft maintenance philosophy. Concepts of "progressive" and "on condition" are becoming more prevalent. Commercial airlines have pioneered the application of a few of these techniques, and as a result, reaped generous savings in related aircraft maintenance costs.

The Navy's current optimization procedures for organizing aircraft maintenance support the Analytical Maintenance Program (AMP) and provides an ideal mechanism for capitalizing on improved NDE techniques. It is recommended that as each aircraft type (A-4, A-6, F-4, etc.) maintenance program is formulated, particular attention be focused to "on condition" maintenance requirements which could be handled more effectively with NDE. The identification of these potentials early in the aircraft's life cycle would enable long term cost savings to be realized. The key is in providing an interface for the maintenance program planners and the NDE technical community to join efforts. For a more in depth coverage of this proposed approach see Appendix B.

B. FLEET NDE EQUIPMENT DEVELOPMENT.

1. NDE Systems Development Cycle. Non-Destructive Evaluation is in many respects an established field. This is the result of a long standing evolutionary process which has resulted in the material quality assurance capability practiced throughout various manufacturing fields. This is not to imply that meaningful or significant improvements are out of reach, but that many requirements can be satisfied with "off the shelf" equipment. In order to place in perspective the various development options available, a

brief review of the research and development cycle is presented. Figure 2 illustrates the generalized R&D cycle consisting of (6.1) research, (6.2) exploratory development, (6.3) advanced development, (6.4) engineering development and (6.6) production development. It should be noted that specific equipment development tasks could range in duration from five (5) or more years to one (1) or less years for rapid response "off the shelf" procurements.

This development cycle is occasionally not compatible with the pace of other factors pertaining to the acquisition of NDE systems. Because the NDE field is dynamic, care must be exercized in selecting development candidates so as not to compete with comercial industries' programs. Rather, attempts should be made to select programs which are of more specific interest to Naval Aviation maintenance programs. Previous experience indicates that attempts to gain marginal performance increases in common Non-Destructive Evaluation equipment often are outpaced by independent commercial developments.

Commercially available equipment systems and projected capability should be utilized whenever applicable and longer term development programs should be addressed to areas of higher aspiration with generally greater associated technological risk.

2. Specific Problem Areas. In addition to certain problems highlighted in other areas of this plan, a few trouble areas require further mention.

a. Restrictive Procurement practices have in the past led to limited participation on the part of recognized name brand suppliers. The net result in the fleet is often less than expected "state-of-the-art" performance. Overzealous application of equipment reliability and maintainability requirements and peculiar hardware system constraints have served to drive up costs of "off shelf capability".

b. The limited commitment which the Navy has made to NDE up to the present fosters another kind of problem. Because there is presently only a limited requirement to practice NDE in the fleet, feedback from the fleet regarding equipment shortcomings is minute, or in most cases, non-existent. This results in the technology development community having to search out field requirements. It is hoped that an expanded commitment to NDE will foster more effective dialogue between the "producers" and the "users".

c. The NDE factions within the Navy are plagued by what may be termed the "chicken and the egg dilemma". Implementation of progressive inspection requirements is often hampered because limited equipment and personnel resources make it impractical to impose additional NDE workload. The development and acquisition of expanded NDE equipment resources is thwarted by the lack of documented requirements and sufficiently trained personnel. Personnel assets are being constrained via the misconception that limited inspection requirement workload does not justify establishing a full time job classification rating, as does exist within the Air Force. This closed loop will probably not be broken quickly, but an awareness of the situation on the part of all three factions will serve to promote long term improvement.

NDE EQUIPMENT DEVELOPMENT CYCLE
(Intermediate & Organizational Level)

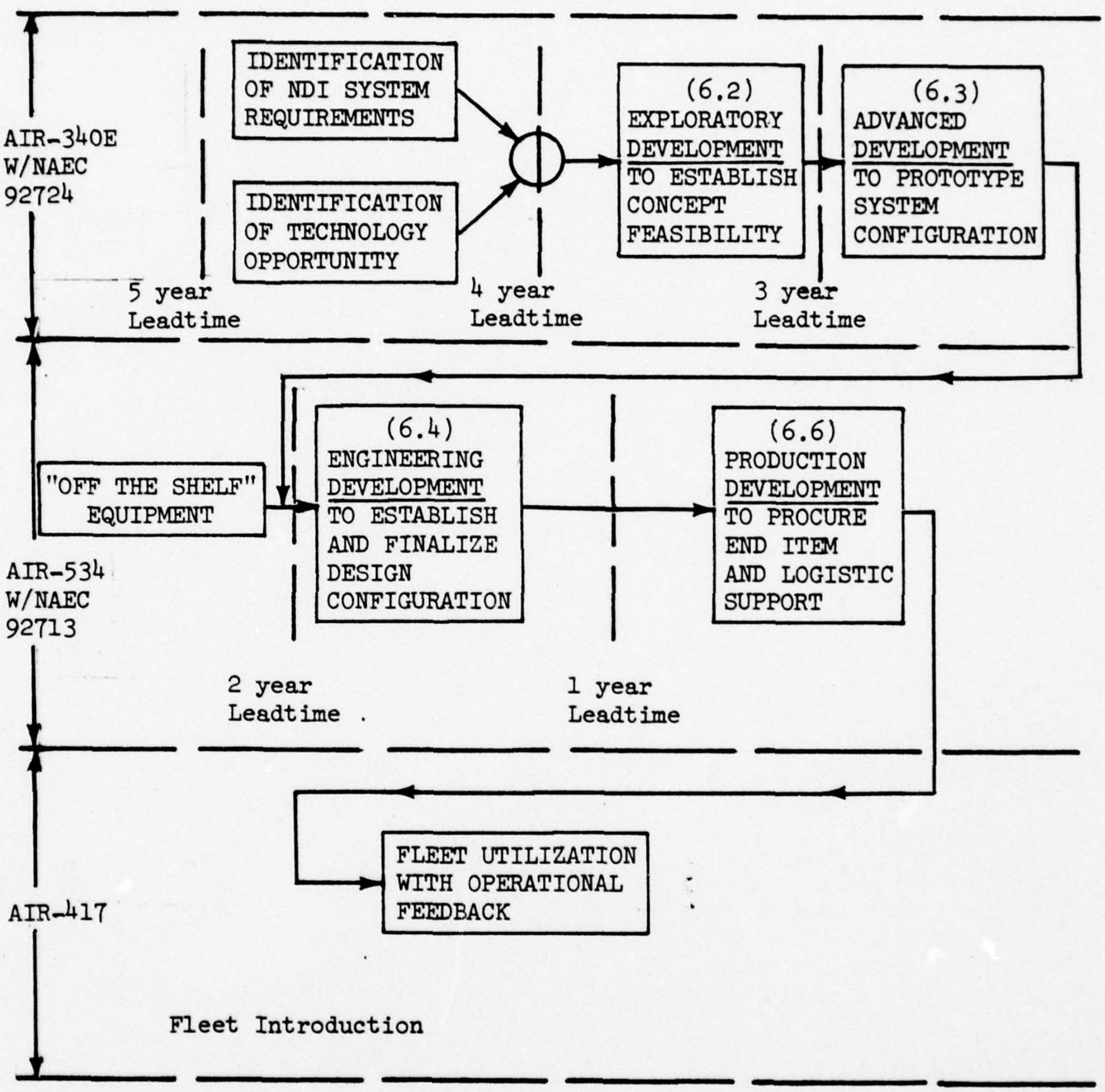


Figure 2.

It is necessary that the established NAVAIR NDT/I Working Group, consisting of AIR-340, AIR-411, AIR-413, AIR-414, AIR-417, AIR-520 and AIR-534 be maintained and promoted in order to ensure that Naval Aviation utilizes NDE to its maximum advantage.

C. ANALYSIS OF REQUIREMENTS

1. This section delineates NDE system capability requirements for the aircraft maintenance support environment, Figure 3. Various inputs from fleet personnel, prime airframe contractors, interfacing DOD agencies and research institutions were analyzed to establish both current and projected NDE requirements.

The discussion of requirements is sub-divided into two specific categories as follows:

a. Current Requirements - Fleet Material Inspection Requirements

b. Future Requirements - New Materials Applications and Advanced Structural Configurations

2. Current Requirements - Fleet Material Inspection Requirements.

a. Detection of cracks in metallic structures - Because there is a lack of quantifiable data regarding fleet NDE crack detection capability, it is difficult to state that the present capability is inadequate. Many components apparently are being adequately inspected. Wheels and bolt holes which are generally components of simple geometry are relatively crack tolerant. However, recent difficulties with TF-30 (F-14) gas turbine components would suggest that small cracks at inaccessible locations or in complex geometry parts are still challenging NDE problems. Conventional NDE techniques are capable of detecting cracks of .05 - 0.25 inches in length. The goal of detecting microcrack growth in the .005 - .05 inch range, presently achievable in the laboratory, for components of difficult geometry, insitu would be very useful and in certain cases necessary with this latest generation of aircraft systems.

b. Detection of Corrosion - Fleet airframe corrosion detection is presently done primarily with visual inspection methods. The most significant problem here is that when suspected corrosion areas are visually inaccessible or even difficult to assess, the corrosion damage goes undetected until the next depot overhaul tear down, with attendant higher repair costs. New approaches are required to accomplish insitu inspection and assessment of hidden corrosion damage on airframe structure. The capability to accomplish this level of corrosion detection and evaluation would minimize the degree of disassembly required during depot overhaul in many cases.

c. Detection and Evaluation of Fatigue Damage in Metals - The detection of early or incipient fatigue damage characterized by microcrack growth is a difficult material condition to evaluate, particularly in the field environment. The incentive, however, is great to accomplish this level of inspection for it would allow remaining component service life to be determined with obvious economic benefits. Many aircraft components are discarded on a time interval basis, not because they can be proven deficient,

NON-DESTRUCTIVE EVALUATION PROGRAM INCENTIVES

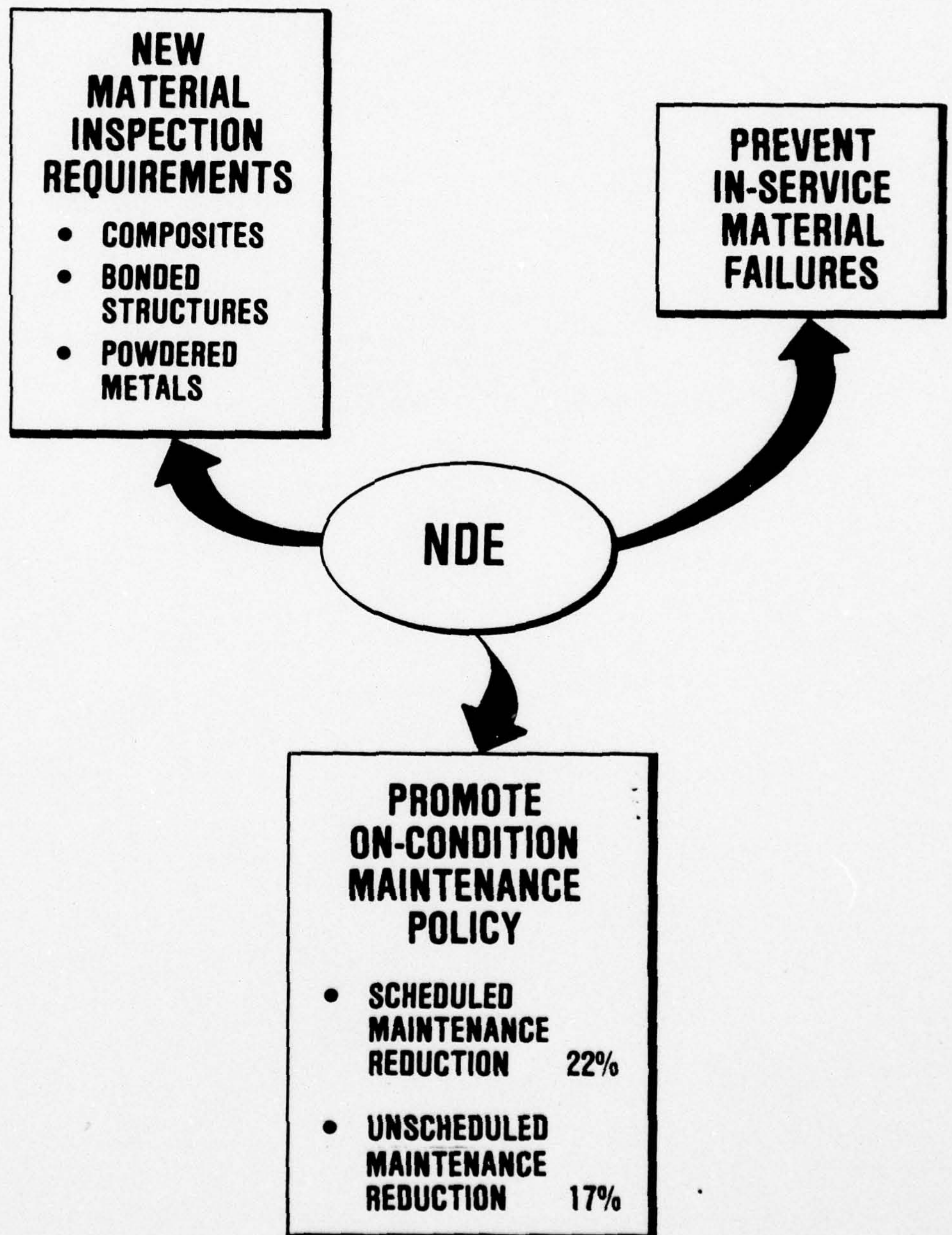


Figure 3.

but because they cannot be proven capable of extended continued service. Better methods for assessing fatigue damage would be most useful for promoting "on condition" maintenance policies.

d. Detection of Disbonds in Composite and Bonded Structures - Present generation aircraft systems utilize composite and/or bonded structures to varying degrees for control surfaces, speed brakes, radar domes, etc. The best available method, as per many fleet personnel, for evaluating disbands in composite structure is the "coin tap". Clearly, better, more definite, less subjective methods need to be developed and applied. In a meeting sponsored by NAVAIRSYSCOM at NAVAIRREWORKFAC, North Island, San Diego, California, "Composite Materials Repair Techniques/Procedures" 16-18 September, 1975 (Reference 2) one of the major objectives or goals for future development was to attain and standardize NDI techniques for various levels of maintenance activity.

Particular attention needs to be focused on means of determining bond strength in cases where intimate material contact does exist.

e. Assessment of Residual Stress in Metallic Structures and Components - "Residual" stresses are an important consideration in the design, fabrication and service life of many structures and components. This is particularly true in the case of modern gas turbine engines where failure from fatigue is anticipated, shot peening or glass bead peening is often used to achieve residual compression stresses, thereby obtaining longer fatugue life. Also, in some instances, development of unfavorable residual stress conditions from service is believed to precede fatigue cracking.

Despite the significance of stresses associated with fabrication of components and residual stress changes resulting from the dynamic behavior of metals in the operational environment, no practical, non-destructive, stress measurement method is available for routine and economical use (Reference 3). X-ray diffraction and other techniques have been addressed, but each has serious drawbacks with respect to field inspection. It would be highly desirable to achieve such a capability for application within the aviation maintenance environment.

f. Evaluation of Heat Treat State and Heat Damage - The utilization of heat treating processes is rather common for the improvement of various material properties utilized in aircraft structures. Environmental factors tending to degrade these material characteristics often go unchecked for lack of adequate field applicable techniques. Better means of assessing heat treatment condition and heat damage in steels, aluminum alloys and titanium alloys are required for the aviation maintenance environment.

g. Crack and Void Detection in X-Ray Transparent Materials - While x-radiation techniques have been employed with significant success to the problems of aviation maintenance inspections, a significant number of potential inspections are not feasible with current in-service radiation inspection systems (x-rays) because the materials involved are relatively transparent to this type of radiation. Emerging technologies (neutron radiography) offer the capability to reverse the relative order of radiation attenuation. Improved imaging of plastics, composite adhesive

bonds, corrosion, water and explosive devices would fulfill these maintenance inspection requirements by complementing x-radiography techniques.

h. Standards Improvement - In the field of NDE standards play a significant role in control of inspection integrity. Unfortunately, "similar" standards often times do not yield similar responses. The need exists to develop high quality standards which are more representative of aircraft materials and their defects.

i. Determination of NDE Reliability - In much the same manner as the aircraft industry has developed reliability figures (reliability and confidence intervals) for manufacturing quality assurance, similar figures need to be established for the Navy's maintenance system.

It has long been realized that the NDE technician is an integral part of any NDE operation within the Naval Aviation maintenance environment. Despite this realization, little has been done to characterize the effectiveness and reliability of the non-destructive evaluation system, consisting of both hardware elements (i.e., ultrasonics, eddy-current, etc.) and the NDE technician.

If the usefulness of NDE is to be expanded to promote extended operational cycles between depot level overhaul and "on condition" maintenance during that operational cycle, a definitive measure of the NDE capability, as it stands today, will have to be established.

3. Future Requirements - New Materials Applications and Advanced Structural Configurations, see Figure 4.

a. "Advanced composite materials are finding ever increasing usage on new aircraft. Their unique combinations of high specific strength and stiffness in conjunction with their potential for reduced production fabrication costs provide strong emphasis for their continued application. From an operational standpoint, however, they present peculiar and non-standard inspection maintenance and repair requirements." (Reference 2) Boron, graphite, titanium, aluminum and glass in conjunction with polyester, phenolic and epoxy resisns are typical composite constitutents. The F-18, presently under development, is typical of the trend toward increased composite materials applications. Projected usage is forty percent (40%) weight of aircraft components in which graphite/epoxy construction is used.

b. Operational experience, although limited, indicates that the following inspection functions will be useful or required:

(1) Measurement of environmental moisture degradation. While not subject to corrosion, composite materials degrade in strength significantly from moisture attack.

(2) Measurement of adhesive bond strength. Current procedures are barely adequate to determine presence of debonds. Better inspection methods, particularly the measurement of bond strength in cases where bonding exists, but cannot be load rated.

COMPOSITE APPLICATIONS ON MILITARY AIRCRAFT

AIRCRAFT	COMPOSITE	APPLICATION	WEIGHT REDUCTION	COST SAVINGS
F-14	Boron-Epoxy	Horizontal Stabilizer Titanium and Boron Epoxy Face Sheets Over an Aluminum Honeycomb Core		
F-14	Graphite-Epoxy	Overwing Fairing MLG Door	22% 8%	18% 17%
F-15	Boron-Epoxy	Horizontal and Vertical	22%	-
F-15	Graphite-Epoxy	Speed Brake	26%	$2,000
F-15	Boron-Epoxy Skin Over Graphite Epoxy Structure	Wing	19%	-
F-16	Graphite-Epoxy	Forward Fuselage and Stabilizers *	20-30%	-
YF-17	Graphite-Epoxy	Ailerons, Flaps, Rudder and Doors *	24% predicted	-
F-18 (Navy)	Graphite-Epoxy	Moldline Skin and Door Applications **	-	-
F-4	Boron-Epoxy Skin Over Aluminum Honeycomb	Rudder	35%	-
A-7	Boron/Graphite-Epoxy Skins Over Graphite-Epoxy Spars and Ribs	Outer Wing *	12%	-
AV-8B	Graphite-Epoxy	Super Critical Wing ***	18%	-
CH-47	Graphite/Boron Epoxy	Main Rotor Blades *	-	-
CH-53	Graphite/Boron Epoxy	Tail Rotor *	-	-
S-61R	Graphite/Boron Epoxy	Tail Rotor *	-	-
BO-105	Graphite/Boron Epoxy	Main Rotor *	-	-
B-1	Graphite/Boron Epoxy	Stabilizers and Fuselage Longerons *	-	-
C-5	Boron-Epoxy	Slat	22%	-

*Test/Development Status
**13.3% A/C Structural Weight - account for 64% A/C wetted surface
***Protype Status

FIGURE 4. COMPOSITE APPLICATIONS ON MILITARY AIRCRAFT

(3) Flaw location and characterization. Before fully effective NDE procedures and systems can be established, critical flaw parameters need to be defined.

c. It would appear from development programs underway, and projected, that a significant composite materials inspection requirement will exist in the future aviation maintenance environment.

d. In the area of advanced metal alloys, research programs are forecasting stronger, lighter weight components. This will cause present detectable flaw sizes to be even more significant in terms of fracture mechanics design criteria. This would portend the requirement for generally greater accuracy, resolution and reliability in NDE system technology.

e. New materials are paving the way for improved structural configurations. Significant performance and cost improvements are being realized with bonded structures, compound bonded or laminated structures, powdered metallurgy, and diffusion weld and forming techniques. The new manufacturing techniques require, to even a greater extent, the improvements denoted earlier in the discussion of "Fleet Material Inspection Requirements".

D. TECHNOLOGY SUMMARY AND FORECAST.

This section provides an overview of the primary technology areas associated with the field of NDE. Projections of future development are offered to establish what options are available for improving accuracy of results, reliability of methods and implementation of new techniques.

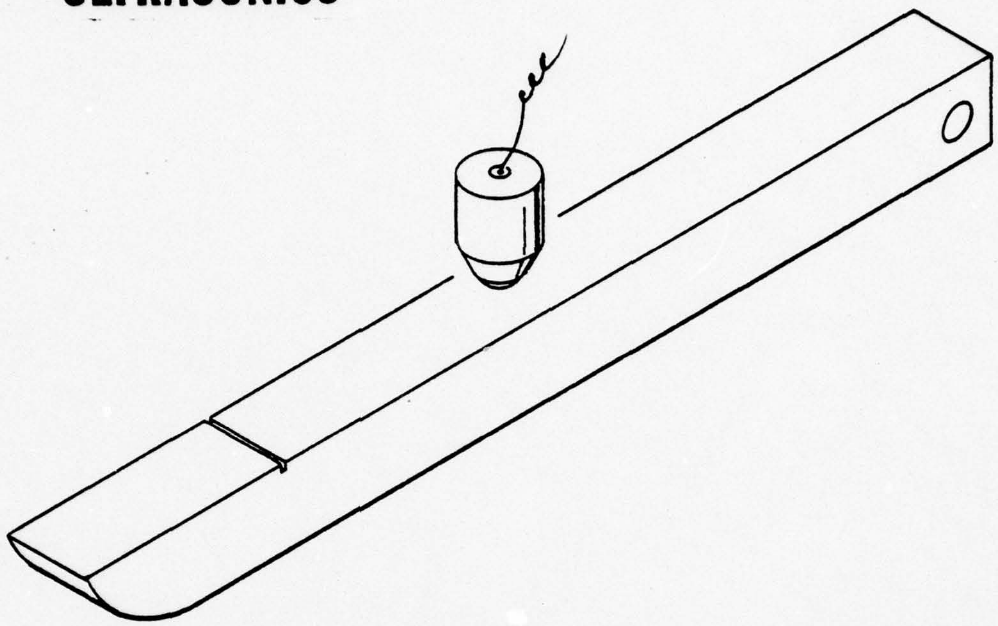
1. Ultrasonics - Ultrasonic inspection has become a widely used airframe NDE technique for locating internal defects, cracks, lack of bond, laminations, inclusions, porosity, and determining grain structure and thicknesses. Ultrasonic systems generate high frequency vibrations (i.e., greater than 30 KHZ) with a transducer, usually piezoelectric, which converts electrical energy to mechanical energy. As these acoustic waves propagate discontinuities of defects cause localized changes in acoustic transmission, giving echoes back toward the transducer, and reduced sound amplitude beyond the discontinuity. Effects are observed on a CRT (Cathode Ray Tube) from three (3) basic configurations:

- Pulse-Echo - Uses single transducer as both transmitter and receiver. Energy is transmitted perpendicular to the material surface. Reflected waves indicate depth and size of defect.

- Through Transmission - Transmitter and receiver are placed on opposite sides of the test material. Defects create an acoustic "shadow" causing a reduction in the amplitude of the received signal.

- Surface Waves - Created by a wedge-shaped coupler between the transmitter and the material. Proper choice provides refraction without penetration allowing waves to trace surface contour.

ULTRASONICS



Recent equipment developments have provided compact battery powered portable units easily capable of use within the aviation maintenance environment. Distance/amplitude, however, remains as the basic criteria for flow and thickness evaluations. While these improvements are not to be minimized, the biggest single problem with field ultrasonic systems remains - they rely heavily on operator skill and scope interpretation.

It is apparent that two basic avenues are available for improving ultrasonic systems: the first, development of improved scanning devices to eliminate operator technique induced variability and the second, the development of signal processing concepts/systems to minimize operator interpretation requirements.

A number of research programs along each of these lines have been probing concepts which could significantly enhance the overall usefulness and effectiveness of ultrasonics for maintenance inspections. A summary of projected impact areas is given:

a. Transducer Evaluation Systems - Government, industry and other users are wasting a great deal of money on transducers that do not work. Systems which will image and analyze ultrasonic beams are technically within reach and could be applied for 100% screening of all transducer procurements as well as periodic in-service calibrations.

b. Ultrasonic Signal Spectrum Analysis - The frequency content of the ultrasonic echo has been demonstrated to be far more accurate in measuring the size of an internal flaw than the conventional echo amplitude. With

the advent of inexpensive microprocessors, various methods of signal analysis (i.e., based on frequency content) can be employed to minimize operator interpretation requirements.

c. Multi-Element Transducers - In conjunction with advanced signal processing, the capability to operate several transducers simultaneously provides effectively an acoustic lens. Transducers grouped in matrix fashion are pulsed and integrated in such a manner as to probe various areas within the material without moving the transducer. An extension of this concept would allow improved display systems, 3-D pictorial readouts.

d. Ultrasonic Standards - Calibration standards, utilized in ultrasonic testing, have recently been severely criticized. Tests conducted by the National Bureau of Standards revealed that there can be as much as an 800% difference in echo amplitude between calibration blocks having precisely the same dimensions. Improvements in this area are expected to include the development of material - independent test blocks and the development of well-characterized fatigue cracks that could serve as a calibration for many NDE tests.

e. Random Signal Correlation - Fundamental limitations on pulse-echo system performance arise from the need to transmit extremely narrow bursts of RF to obtain fine range resolution and the need to wait until the most distant echo has returned before transmitting another pulse to avoid range ambiguity problems. The use of correlation and time integration techniques in the laboratory environment has yielded signal-to-noise ratio enhancement approximately 10^4 times greater than conventional pulse-echo detection systems.

Adaptive signal processing circuitry has also shown promise for enhancing ultrasonic inspection capabilities. Microcircuit technology appears to hold the key for realizing the next quantium jump in portable ultrasonic flaw detector performance.

f. Mechanical Scanning Devices - As closer tolerance inspection techniques have become a reality, the need to replace handheld and positioned transducers with mechanical scanning devices has been recognized. To date circular "roto-scanners", for use on installed fasteners, and linear X-Y scanners for use on planer surfaces, have demonstrated the feasibility of mechanical scanning systems. Much has been done in the manufacturing environment to capitalize on automated inspection systems and the extent to which these kinds of systems will be applied to field servide is more application constrained than technology constrained.

g. Electromagnetic Non-Contact Transducers - Coupling problems associated with conventional transducer technology has prompted the development of electromagnetic transducers which can generate ultrasonic waves at the surface without making physical contact. The electromagnetic transducer uses a small coil excited by radio frequency energy in combination with an electromagnetic field to generate eddy currents in the material which react with a static magnetic field to generate acoustic waves. Additional development is required in this area, however, before replacement of piezoelectric transducers is to be considered.

This summary is indicative of the body of recent research finding which will provide the basis for ultrasonic equipment performance improvements over the next decade. While ultrasonics has proven extremely useful up to the present, the future outlook portrays an even greater contribution to structural quality assurance and improved maintenance practices particularly in the aviation maintenance environment.

2. Eddy Current - Eddy-current inspection, a method of locating surface or subsurface flaws in electrically conductive materials and also evaluating such material characteristics as hardness, heat-treat condition and other metallurgical conditions is finding new applications in the aircraft maintenance environment. A large impetus for these applications is that eddy-current systems are relatively simple and conducive to in-site inspection procedures requiring minimal preparation.

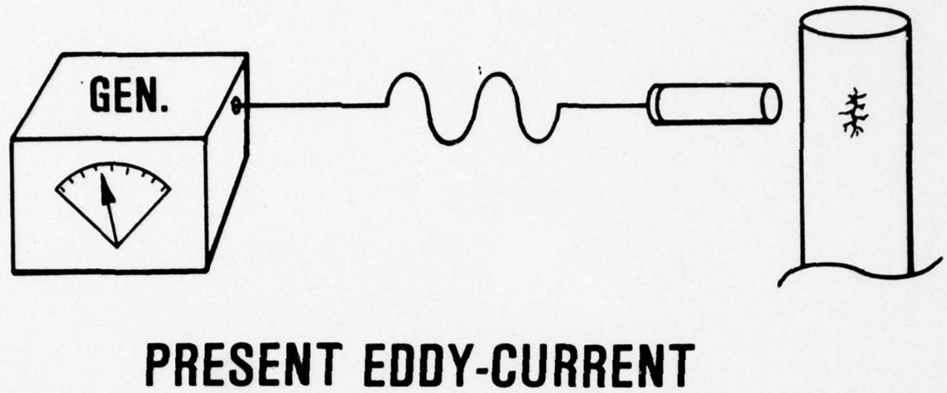
A field produced by one or more coils energized with alternating current, frequency varying from 50 HZ to 6 MHZ, is generated within the component being tested. Discontinuities produce changes in coil impedance which are sensed by meters, recorders or oscilloscopes.

Recent equipment developments have provided compact battery powered portable units as well as units which incorporate expanded frequency spectrums (low, 50 HZ - high, 6 MHZ) and phase angle information. A summary of technology impact areas which will influence the development of improved eddy-current inspection systems is given below:

a. Multi-Frequency/Pulsed Generators - Present eddy-current systems utilize a single frequency generator which is optimized for a particular application; high frequency for surface evaluations and low frequency for sub-surface evaluations. The ability to adequately evaluate defect and material characteristics requires more than a point optimized system. For this reason, multi-frequency generators are being investigated to compile a composite defect image which would be significantly more representative of the actual material condition. An extension of this concept is pulsed signal generators which utilize a square wave input with "infinite" frequency content and selective output signal processing to achieve a further expanded composite image. Signal processing remains the major complication with micro-processor technology providing potential solutions. See Figure 5.)

b. Controlled Reluctance Eddy-Current Generators - The two most critical limitations of eddy-current inspection systems are edge effect and practical sensitivity. In conventional probes, if the probe is brought within 1/4 inch of an edge, the signal level will begin to change and this change in signal level will obscure a crack signal. This is particularly troublesome since fatigue cracks are nearly always generated at stress risers such as steps, holes, or other geometric discontinuities. Also, with conventional probes the variations in signal amplitude due to normal material variation limits the fatigue crack detection capability to approximately 30 mils long by 15 mils deep cracks.

The edge effect can be reduced and the practical sensitivity can be increased by controlling the location and spatial extent of the magnetic reluctance associated with the eddy-current generator.



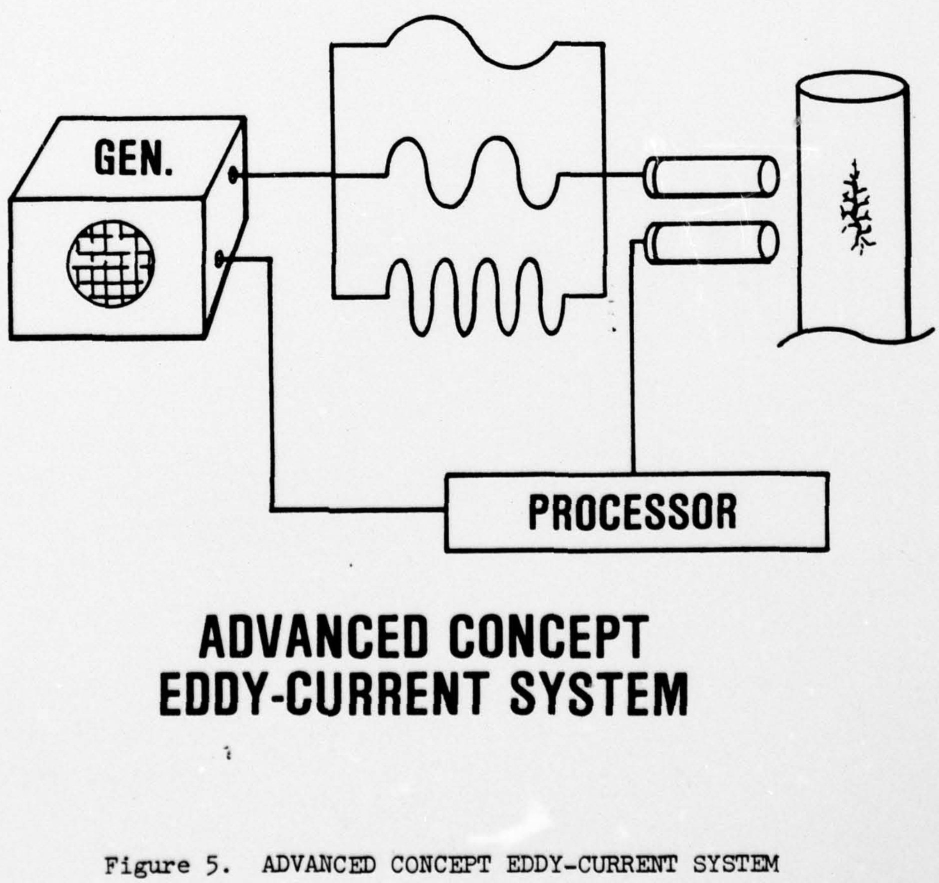


Figure 5. ADVANCED CONCEPT EDDY-CURRENT SYSTEM

By combining high and low reluctance probe materials the area over which the eddy currents are generatyd is reduced, thus minimizing edge effects and increasing the sensitivity to flaws in the region where the eddy currents are generated.

This additional refinement in probe design will allow more exacting inspections to be performed where precision is more essential than broad coverage.

Recent lab results indicate an order of magnitude increase in sensitivity available with controlled reluctance probes.

c. Eddy-Current Standards - As with other techniques, eddy-current methods have exhibited the need for improved standards. Primary areas requiring attention are conductivity of non-ferrous materials and flaw detection in ferromagnetic materials. More adequate standards, both reference and calibration, will be required as the inspection sensitivity and resolution of eddy current systems are improved.

It is expected that future directions will also be toward methods for the calibration of eddy-current test equipment.

d. Automated Scanning Devices - Because of the inadequate nature of manual scanning, a number of automated scanning devices have been investigated. Bolt hole scanners have recently been developed and are being utilized to improve inspection reliability by assuring complete scan coverage and uniform surface mapping. More versatile derivatives of these systems will be available whenever the need for a programmable, repetitive inspection device warrants their development expense.

"Paint-brush" or multi-coil probes are also a distinct possibility when there is a requirement to decrease inspection time for flat surfaces without reducing detection capability.

3. X-Radiography - Radiography is a technique which has been around for quite a while. This makes it particularly difficult to forecast the development prospects because the field is less dynamic than other emerging technologies and many of the remaining problems are the more difficult ones to solve. Current areas of interest are highlighted here as a means of providing perspective, indicitive of future applications and potential usefulness.

a. Micro-Focus - A recent development in industrial radiograph, micro-focus systems utilize appropriate electronic circuitry to collumate and simultaneously alternate the X-radiation beam in order to provide higher image resolution, particularly with less than optimal film placement arrangements. This higher resolution is available over a smaller area and is generally most advantageous for localized high resolution inspection requirements or when radiograph enlargement is anticipated. Present micro-focus systems operate up to 100 KU and 1 ma.

b. Image Enhancement - Image processing has been used for some time on biomedical radiographs as well as other photographic materials. Application to industrial radiographs has been limited but the potential

exists with a number of systems to improve image quality in order to reduce the burden of interpretation in cases where information is present but difficult to visualize.

There is a variety of approaches to image processing. Generally the image is processed by scanning the initial radiograph with either microdensitometers, television scanners, light or laser beam scanners, to generate an electrical signal output which is then fed to an analog processor for edge enhancement or a digital processor for color coded contrast or more involved computer data manipulation. The refined signal is then reconverted and displayed with either cathode-ray tubes, photographic write systems or other methods.

Reference 4 gives a detailed analysis of "Image Processing of Industrial Radiographs". This investigation concluded that, in general, the television systems have certain desirable features which make their application more feasible than other systems for aircraft maintenance inspection requirements. It is expected, however, as more powerful data processing systems are developed and refined, the usefulness and efficiency of various approaches could change.

c. Isotope Radiography - Gamma-ray or isotope based radiography is not a new concept but one which has been used very productively on a limited basis by the airlines for internal engine inspections. The particular advantage of isotope techniques is that they allow inspection of limited access areas which would not be feasible with conventional x-ray tube systems. The most productive applications have been hot section and burner can analysis which otherwise would be handled by engine disassembly.

These isotope systems require stringent safety controls and well trained operators as the isotopes, Cesium 137, Cobalt 60, or Iridium 192 are always actively decaying and must be effectively isolated from personnel in the surrounding area.

This technology has been successfully utilized to extend engine overhaul periods for commercial airliners to effect a considerable reduction in maintenance expenses.

The state-of-the-art of isotope radiography is not expected to change dynamically but the potential for new effective application does exist and will provide the impetus for further investigations.

4. Neutron Radiography - Neutron radiography is emerging as a versatile cost saving technique for inspection of aircraft structures and components. Neutron radiography complements x-radiography because of the relative absorption characteristics of most elements are essentially reversed. The outstanding potential of N-ray is its ability to see through metal aircraft structures for hidden defects, thus minimizing disassembly to inspect procedures. (Reference 3)

Neutron radiography has proved advantageous for inspecting airframe structures for corrosion, entrapped water and hydrocarbons, composite airframe structures for disbonds and defects in explosive devices.

Tests conducted on a Grumman E-2e wing indicate that neutron radiography could save as much as $100,000 per aircraft inspection compared to presently used procedures. (Reference 6)

The explosive components from the pilot ejection system for the F-14 and other new military aircraft require neutron radiographic inspection to assure that the explosive content is correct. There is no presently known non-destructive test other than neutron radiography that will accomplish these inspection objectives. See Figure 6.

The primary technological impact areas associated with neutron radiography as it applies to aircraft inspections are summarized below:

a. Californium - 252 Systems - The advent of the man-made radiosotope Californium-252 has made feasible airframe inspection employing similar procedures as gamma radiography. The isotope pellet with a half-life of 2.6 years, is generally housed in a heavily shielded enclosure and transported by remote control to a camera for inspection exposures. The result is a bulky system which requires considerable precaution in using. Presently these systems constitute the only operational "portable" field inspection capability available for aircraft inspections.

The major expense involved with isotope neutron radiography is the cost required to replenish the Californium periodically and the investment required for storage devices and exposure room facilities if the inspections are to be implemented within close proximity to personnel.

b. Neutron Accelerator Tubes - The high cost and cumbersome handling problems associated with Californium-252 based systems has prompted the consideration of alternative approaches. The charged-particle accelerator neutron generator, with its characteristic high neutron flux capability, is a potential source for a low-cost portable neutron radiography system for field nondestructive inspection. The use of such generators in this application has remained largely unexplored to date. Accelerators, such as the Van de Graaff and Cockcroft-Walton type neutron generators, are well developed neutron sources, but they require further development in terms of neutron moderation, collimation systems, and optimum operating procedures. Although many similar developments have been, and are being carried out for CZ-252, there are differences for the accelerators that require attention.

c. Image Enhancement - Once a neutron radiograph has been processed, techniques of image enhancement which are employed for X-radiographs may also be applied. For further detail, see "X-Radiograph Section".

d. Neutron Imaging Films - Up to the present, all films utilized for recording neutron radiography have been conventional x-ray film utilized with a converter screen. The role of the converter screen is to change the neutron image to alpha, beta, or gamma radiation which is detectable by a wide range of x-ray films.

Recent development in films, however, offers the potential of a neutron sensitive emulsion with improved resolution and recording efficiency (90%). Exposure times have the potential of being reduced by a factor of ten (10).

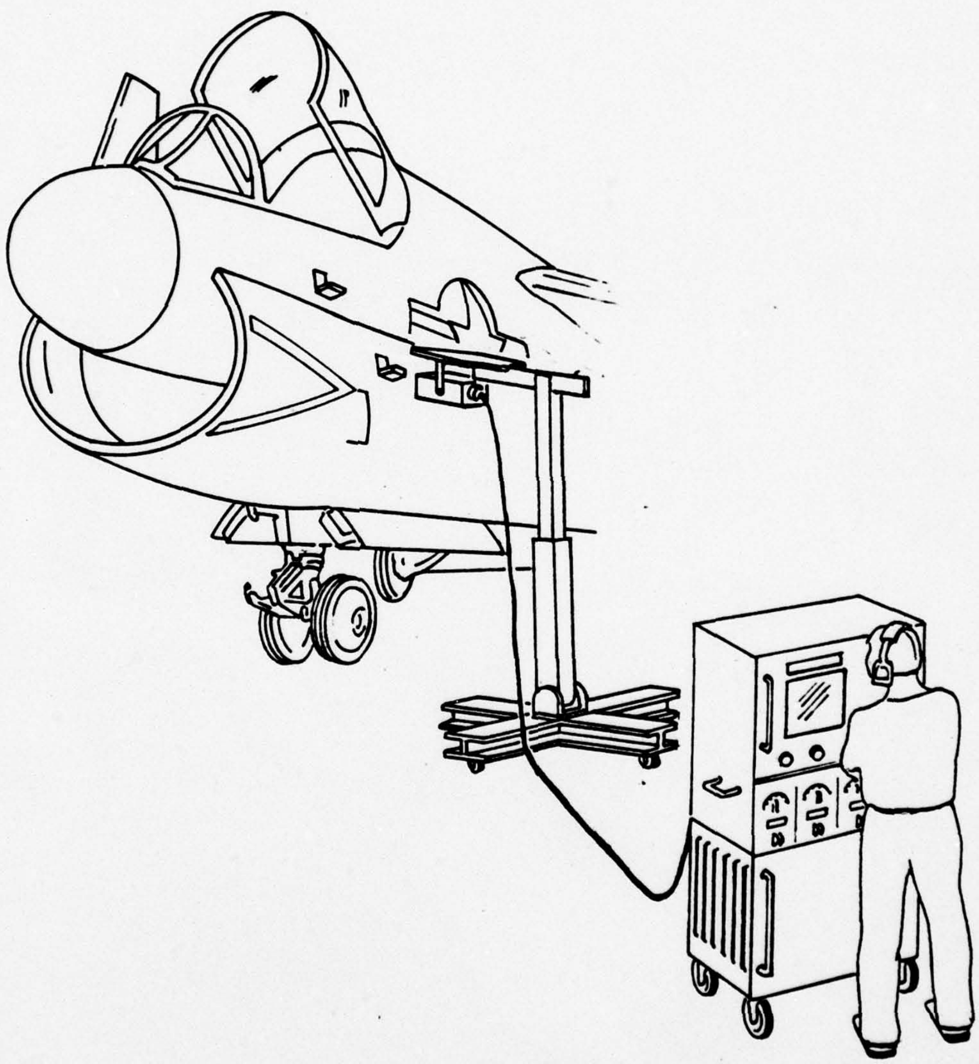


Figure 6. NEUTRON RADIOGRAPHY PORTABLE ACCELERATOR CONCEPT

These developments spurred on recently by the film manufacturers realizing that the market potential for such films is substantial and expanding, will provide a significant contribution towards the economical and efficient application of all neutron radiography systems.

5. Acoustic Emission - Acoustic Emission (AE) is a recent addition to the available nondestructive evaluation techniques applicable to aviation maintenance problems. The technique is unique among most in that it identifies and locates only flaws of a serious or dynamic nature. The basic principle of acoustic emission is the utilization of high frequency (100 KHZ - 1 MHZ) energy bursts which occur at the onset and continuation of material failure to signal structural degradation. These energy waves travel through the structure and are picked up with piezoelectric transducers which convert the signals to electrical pulses which are then processed and analyzed in a number of ways. See Figure 7.

There has been a tendency to widen the use of the term "acoustic emission" to embrace all acoustic signals that may be detected with a normal AE apparatus. High pressure leaks, boiling and other phase transformations, corrosion processes, the detection of incipient failures in bearings and other rotating parts are a few of the additional applications which serve to indicate the versatility of this emerging technology.

A summary of projected technology trends, which if capitalized on, would serve to significantly enhance the Naval Aviation Support NDE capability are given:

a. Portable Systems Development - Present AE systems are not readily transported. By taking advantage of miniaturized solid state electronics and programmable inspection systems, a versatile yet compact analyzer would be realized. The availability of such a unit would provide additional opportunities for "on condition" maintenance strategies.

b. Advanced Signal Processing - Recent developments in the field have expanded analysis of acoustic emission signals to include frequency distribution, amplitude distribution, rise time discrimination, spatial discrimination, and others. "Signal interpretation is currently recognized as the most important frontier of AE technology". (Reference 7) An empirical approach can often be applied successfully to a simple system or by a sufficiently experienced operator. But there is a constant demand for more rigorous and precise ways of interpreting AE and assessing defect severity or structural integrity.

c. Application Analysis - Acoustic emission is presently experiencing a rapid growth in applicational developments. Areas which could be profitably pursued to improve efficiency of airframe diagnostics are:

- airframe corrosion detection in isolated areas
- bearing fault analysis
- hydraulic system diagnostics
- crack detection in metallic airframe structures and related components
- fault detection in composite material airframe structures.

NDE SYSTEMS DEVELOPMENT

ACOUSTIC EMISSION SYSTEMS

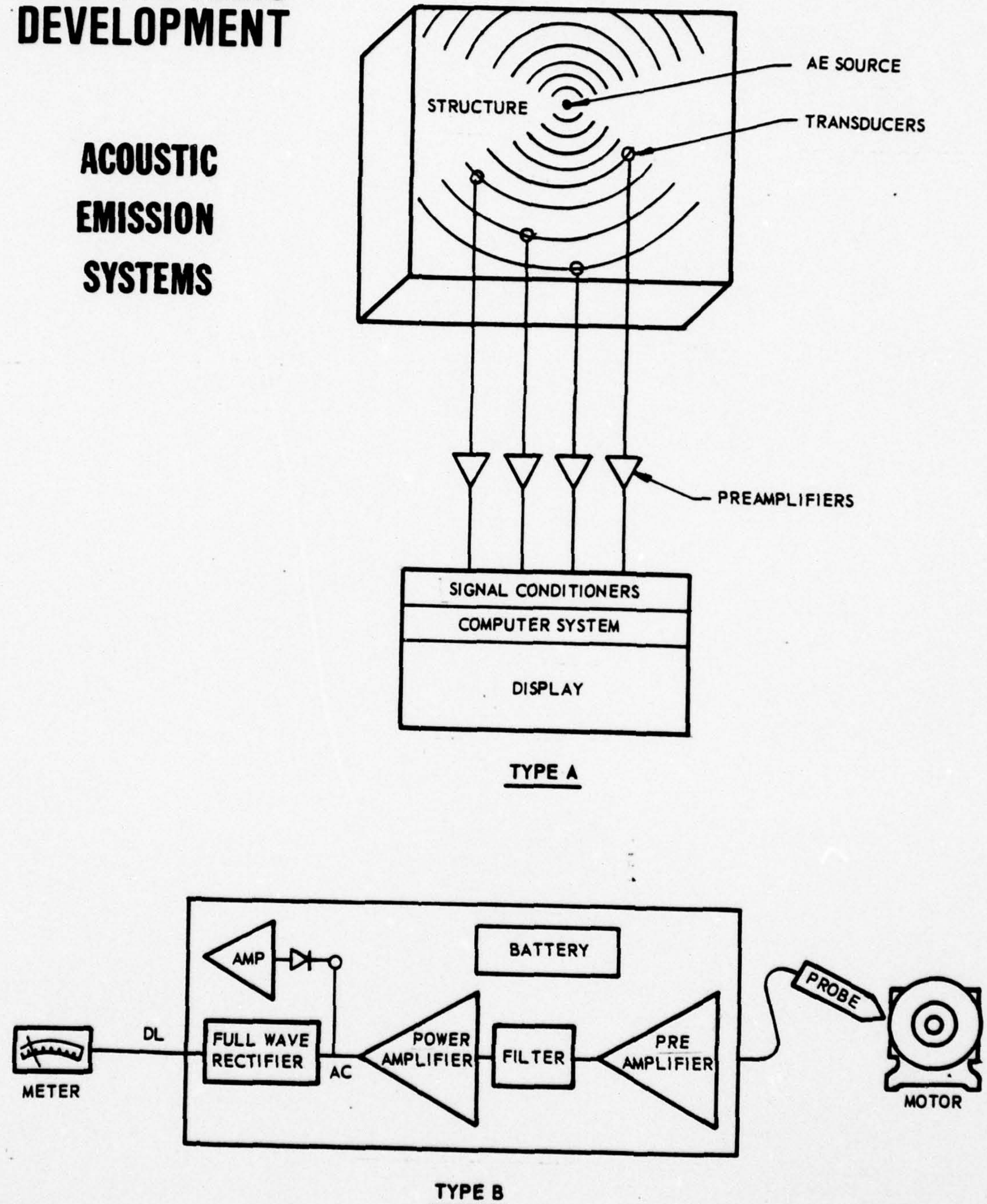


Figure 7. ACOUSTIC EMISSION SYSTEMS

Specific attention will have to be focused on appropriate means of stimulating elements under evaluation and establishing rejection criteria based on acoustic emission signature criteria.

6. Magnetics. Magnetics is a term which encompasses a number of specific NDE procedures. Magnetic particle methods, Barkhausen noise, magnetic pertibation all constitute magnetic inspection techniques. Because of significant differences between these methods they are being addressed separately.

a. Magnetic Particle - Magnetic particle inspection technology in many respects is well established and practiced in a routine fashion for many applications. Yet, statistical surveys indicate a wide variation in detection capability. This is not particularly surprising because the common magnetic inspection methods rely on non-visable magnetic field/material interaction characteristics and a high degree of visual interpretation of indicated results. Each of these areas provide significant difficulties in terms of controlling inspection reliability. It is expected that the most meaningful improvements could be made regarding magnetic field characterization. Many of the industry-accepted magnetic particle techniques are based upon empirical results obtained from simple shaped parts. Work at McDonnell Douglas indicates that the general rules developed by industry for magnetic particle testing are inadequate for inspection of some complex geometric parts.

Because of the existing wide spread application of magnetic particle inspection systems, it is expected that manufacturers of this equipment will provide significant evolutionary improvements to the basic hardware systems.

b. Barkhausen - The rapid and reliable measurement of residual stresses in structural components is still an unsolved aspect of nondestructive testing. Barkhausen noise has been addressed as a practical means of evaluating residual stress in ferro-magnetic materials.

Barkhausen techniques exploit the fact that magnetization in a specimen does not increase in a strictly continuous way, but rather by small, abrupt, discontinuous increments called Barkhausen jumps, which are caused principally by the movements of mobile magnetic boundaries (Black Walls) between adjacent magnetic domains. The direction and magnitude of the mechanical stress/strain existing in a microscopic ferromagnetic specimen strongly influences the detailed dynamics of the domain wall motion and correspondingly influences the Barkhausen noise.

Present systems have demonstrated limited success with regard to residual stress quantification. Future concepts to be addressed to improve this performance are:

- feedback circuit incorporation to correct magnetic field variations caused by component geometry variations, material factors, etc.

- lift off compensation circuitry

- noise pulse analysis/signal processing to improve system sensitivity and reliability.

Barkhausen does offer the potential for subsurface residual stress evaluation, a desirable capability.

The requirement for additional research in this area appears to be secondary to the need for application investigations.

7. Penetrants - Penetrant technology is a well established tried and proven sector of non-destructive inspection. Over the years it has progressed steadily to the point where most current developments, with a few exceptions, deal with specific refinements to the chemical formulations (liquid vehicles), dye chemistry, and indication characteristic stabilization. These trends are expected to continue, being supported by a broad based industry demand.

Two potentially notable exceptions to this incremental development trend are chemical amplification processes and Krypton Emission Techniques - each are further described below.

a. Chemical Amplification Processes - A difficulty with existing penetrant techniques is that when the crack size is very small, there is often not enough penetrant in the crack to produce a visible reaction in the developer. To overcome this problem, methods involving (1) chemical amplification and/or (2) physical amplification have been proposed. Various combinations of catalysts, solvents, polymers, dyes, wetting agents, and heating and illumination conditions have indicated an order of magnitude (1 OX) or better detectability amplification.

b. Krypton Emission Technique - The Krypton Emission Technique (KET) process is similar to a dye penetrant system. KET takes advantage of the fact that all materials have surface-absorbed gases which can be replaced with radioactive gases. The concentrations of these gases in cracks and porosity are readily detectable using conventional film autoradiography or electronic scanning, (Reference 8). Parts to be inspected are first outgassed in a vacuum chamber, followed by exposure to krypton gas (KR-85). The gas is cryogenically trapped and the parts are then removed for imaging.

The system can measure defects with dimensions measured in millionths of an inch. A crack of width 10^{-6} inches would generally be magnified 10^4 times to a width of 0.01 inches. Crack cleanliness poses no difficulties since foreign material in a crack only serves to provide additional absorption sites for the gas.

Relatively speaking, the process is cumbersome and costly but it is probably the most definitive crack detection process available.

8. Thermography - Thermography is a collection of techniques which utilize temperature variations to indicate structural/material characteristics of interest. The following sub-categories of thermographic nondestructive evaluation are summarized as an indication of advances in the state-of-the-art which are applicable to aircraft inspection problems.

a. Infrared Cameras - Infrared cameras or thermographs are scanning radiometers which use optical components to mechanically scan the radiometer's output through a television type scan pattern. Absolute temperature levels of objects within the range of -30°C to +2000°C can be measured with maximum sensitivities of .2°C.

Applications to aircraft maintenance which have been successfully demonstrated include inspection of tires (References 9 and 10), detection of alpha segregation in titanium discs (Reference 11), evaluation of honeycomb panel bonds in airframe structures and helicopter rotor blades and detection of wing tank flaws (Reference 12).

On the complete power plant, Vanzette (Reference 13) has developed a Turbine Thermal Monitor which allows monitoring the temperature of rotor blades in an operating gas turbine engine. Hot blades have been distinguished from others moving at a rate of 50,000 blades per minute by incorporating fiber optics and IR scanners.

b. Photochromic Paint and Liquid Crystals - Some of the most elegant, flexible, and relatively inexpensive NDT developments involve the use of photochromic chemicals and heat sensitive liquid crystals to highlight thermal anamolies in materials.

Demonstrating less sensitivity (± 1° to 5°C) these contact methods have been applied for evaluation of debonded areas, skin voids, lack of honeycomb to skin adhesive fillets, metallic inclusions, water in honeycomb, and resin rich areas.

However, in both methods the changes in color do not provide quantitative values. Further research is required toward calibrating the response of a given photochromic paint or liquid crystal mixture on a given substrate under a given set of conditions and agreat deal of standardization of formulations best suited for differenct temperature or structural applications is necessary.

c. Microwave Thermography - Microwave thermography is a new method for sensing subsurface temperature distributions, presently being applied in bioengineering for the detection of thermal anomalies such as malignant tumors. The partial transparency of selected materials to microwave radiation implies that thermal radiation generated internally may escape from the surface. A measurement of the microwave radiation intensity is therefore related to the temperature along the path of escaping emission. Specific application to aircraft inspection requirements has not yet been accomplished, but it is suspected that aircraft systems, characterized by large temperature gradients could provide profitable areas of investigation.

9. Optical Systems - Optical systems are an extension of the oldest and most widely applied non-destructive evaluation technique known, visual inspection. While most all of the NDE techniques rely on some degree of visual interpretation, optical inspection systems strive to provide visual access to otherwise hidden areas. The most common optical system in use is the borescope. Borescopes have been utilized for many applications and it is expected that industrial suppliers will continue to refine and improve commercially available systems. A few areas which could be explored for improving the present optical inspection capability are given:

a. Low Light Television System - Developments in high sensitivity miniaturized television systems have provided an inspection capability potentially applicable to field inspection requirements. It would be necessary to (1) evaluate the applicational effectiveness and (2) potential field durability of this rather sophisticated approach in situ aircraft inspections.

b. Stroboscopic Inspection System - "FOD, which is the most prevalent engine failure mode (Reference 14), is probably aggravated by current inspection methods which require personnel entry into the engine intake ducts. The optical FOD detection technique outlined below allows for visual inspection of the first stage from the intake proper without personnel entry. An optical sighting device consisting of a terrestrial telescope and a variable time base strobescopic light source is directed at a segment of the first compressor stage. In all cases the intake configuration of current Naval aircraft permits line-of-sight alignment from a position at the inlet to a segment of the first compressor stage. The compressor is rotated at a sensibly constant rate in the starting mode and the light source is synchronized to the rotational frequency. By means of the telescope, a magnified inspection is made and tracked through all blades.

c. Borescope Refinement - Improvements to borescopes are generally expected through improvement in optical transmission efficiency. Investigations would include optimum fiber shape, fiber diameter, fiber material and fiber packing arrangements. In addition, stereoscopic and zoom capable systems could be evaluated.

10. Acoustical Holography - The development and application of acoustical holography inspection systems (Reference 15) has progressed recently with respect to aircraft maintenance operations. Several recent investigations have demonstrated the feasibility of detecting inner surface corrosion on the P-3 aircraft and incipient fatigue cracks in wing stiffeners on the A-6 aircraft (Reference 16).

A schematic diagram of an acoustical holography system is depicted in Figure 8. The system consists of a rectilinear mechanical digital scanner, an electronic signal processor, and an image display oscilloscope. The scanner contains the ultrasound source (transducer), whose output is focused into the area under inspection through a water coupling. The electronic signal processor, which also contains the electronic ultrasonic pulse-generating components, detects and converts pulse-echo signals, reflected from structural surfaces and abnormalities located on or within these structures into usable information. The image display components present the detected information on storage oscilloscopes.

This type of acoustical imaging device can be used for a variety of nondestructive inspections on metallic plastic laminated structures and composite materials.

These systems are presently rather costly (approximately $50,000), however, it is expected that as the applicational base expands the cost/volume relationship would serve to reduce this figure.

SCANNED ACOUSTICAL HOLOGRAPHY IMAGING SYSTEM

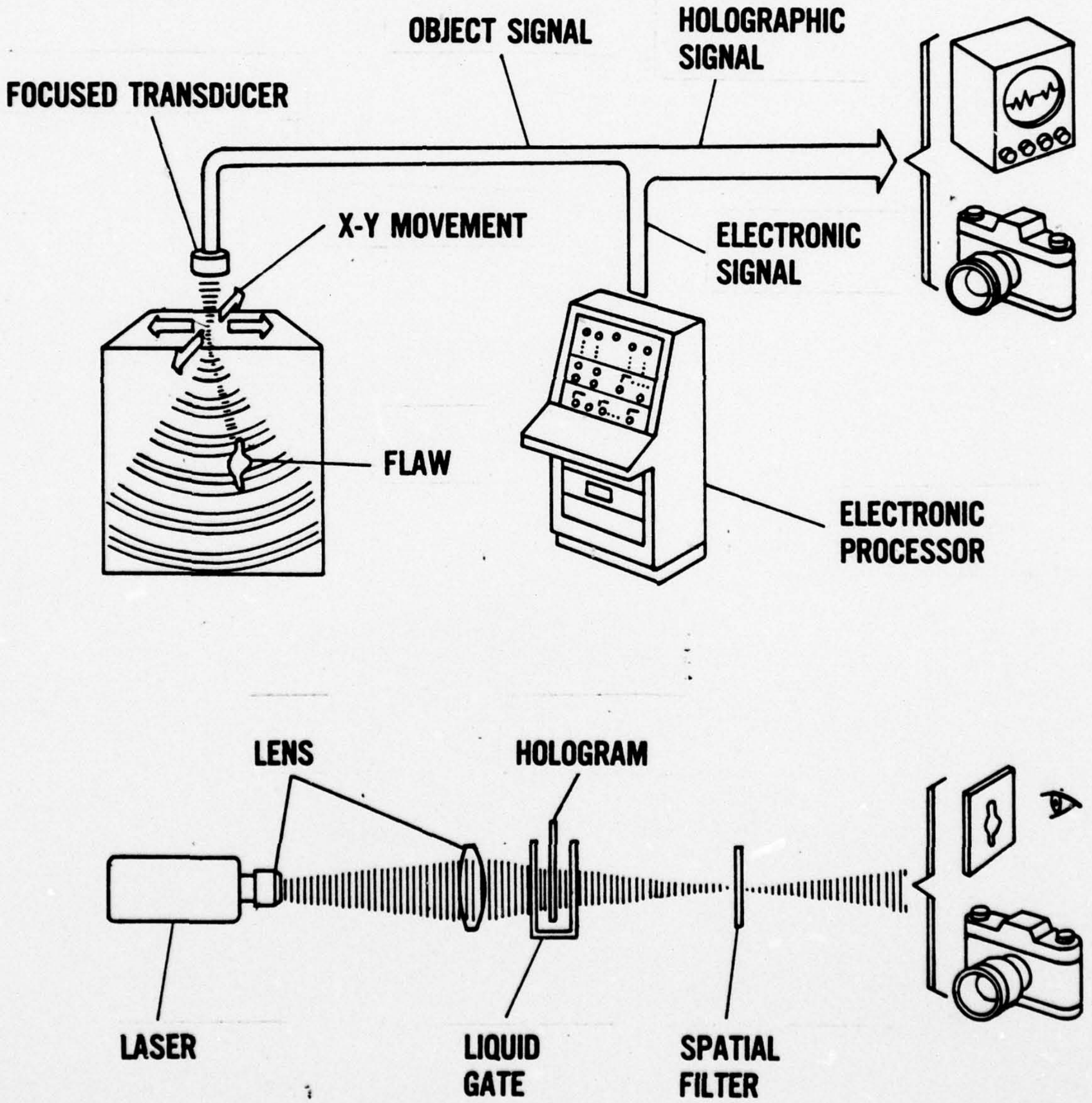


Figure 8. SCANNED ACOUSTICAL HOLOGRAPHY IMAGING SYSTEM

11. Optical Holography - Holography is a lensless imaging process in which total record of the phases and amplitudes of light waves reflected from an object are recorded on photographic film. Then by a reconstruction process, it is possible to reproduce a three-dimensional image of the object.

Holographic interferometry has been applied to problems of material testing and experimental stress analysis. Its key features are high sensitivity and applicability to testing of objects with complex shape and surface structure.

There are principally two classes of optical holography, continuous wave and pulsed. Continuous wave holographic NDT imposes severe restrictions on the environment under which it can be utilized. Mechanical isolation and elimination of air drafts and temperature gradients, etc., are required for satisfactory performance when one uses a continuous wave holographic nondestructive inspection process. Continuous wave holographic nondestructive testing process has offered several advantages and has indeed made a very worthwhile contribution to the NDE area. It will continue to serve as a recognized nondestructive technique in the laboratory and also where one can indeed provide the necessary controlled environment. To overcome the need for having a controlled environment, pulsed laser holographic interferometry can be applied to nondestructive evaluation. Since the light durations from the pulsed laser are extremely short, approximately 50 panaseconds or less, one does not require a controlled environment. It is this aspect of the technique which will permit use of pulsed laser holographic NDE system not only in the laboratory but also in manufacturing.

The principal limitation is the dependence on operator interpretation of hologram fringe patterns which tends to become extremely cumbersome for repetitive inspections.

12. Mechanical Impedance - "One of the more recent techniques to find widespread applications in NDE is that of mechanical impedance or vibration measurement.

Every mechanical structure whether complex, like a large building, or very simple, like a thin disc, has mechanical vibration characteristics which can be determined experimentally and mathematically. Factors such as mass, stiffness and viscous damping all form part of the structural characteristic giving rise to natural resonant frequencies, quality factors and damping factors.

A structure may be forced to vibrate at a particular natural frequency in order to make an assessment of the quality of the structure. Deviation of the actual natural frequency from the anticipated frequency may be used as a measure of the acceptability or otherwise of a particular aspect of the structure.

Application of the technique to aircraft engineering includes the testing of bonds between face sheets and honeycomb core both for metallic and non-metallic types. Recent developments include carbon fiber and CFRP laminates together with void detection in polyurethane foam to a depth of 10 min." (Reference 17)

E. MATRIX SUMMARY OF TECHNIQUES VS REQUIREMENTS. Table 1 provides a summary description of the applicational potential for the various technology areas as they relate to specific problems regarding Navy aircraft operational failures. This should not be construed as current operational capability in every case, but rather an indication of what emerging technology could provide with appropriate development support.

F. ALTERNATE SOLUTIONS TO REQUIREMENT DEFICITS. This section describes the alternatives available in dealing with the NDE support function provided the intermediate and organizational levels of maintenance. The alternatives are based on the premise that an adequate non-destructive evaluation capability is not provided, for whatever reasons. These alternatives are more on the order of results. This is the case because the complexity of modern aircraft weapon systems present formidable inspection requirements which are not always covered by a number of technique options. In general, it is fortunate to have available a single inspection option; if this is not provided, it generally results in a restriction of operational capability. The following consequences are envisioned or in some cases already present, as a result of not providing an adequate NDE support capability.

1. Expanded "NARF Team" Support - If the intermediate or organizational levels of maintenance are not capable of providing the required NDE support, the next higher level, depot maintenance, will generally be called upon for assistance. This is accomplished via "NARF Teams" which are dispatched from the cognizant Naval Air Rework Facility to the operational facilities experiencing difficulties. The principle drawbacks associated with this arrangement are:

a. It is extremely expensive to cover travel and salary expenses for NARF personnel dispateched to problem sites.

b. Provides limited responsiveness because of limited available personnel and inherent transportation delays.

c. Provides only for minimum requirements (problem areas); cannot be called upon to implement programmed maintenance efficiency inspections.

d. Minimizes fleet inputs by taking intermediate and organizational level personnel out of the control and feedback loop.

2. Restrict Operations - Because the majority of present and potential NDE inspections are critical to operational safety, they command sufficient attention to demand some maintenance action. This may take the form of a routine NDE procedure when personnel and equipment resources permit or a more involved disassembly to inspect operations which generate a counterproductive maintenance situation. When component disassembly and removal procedures fail to permit adequate inspection, maintenance personnel are forced to remove "suspect" elements and replace with inventory spares. These disassemble to inspect and remove/replace maintenance actions consume inordinate amounts of time and material resources which restrict operational capability.

Table 1. MATRIX SUMMARY OF TECHNIQUES VS REQUIREMENTS

MATERIAL/CHARACTERISTICS	Ultra-Sonics	Eddy Current	X Ray	N Ray	Acustic Emission	Magnetics	Penetrants	Thermo-graphy	Optical Systems	Acoustical Holography	Optical Holography	Mechanical Impedance
STEELS												
. Fatigue Cracking	•	•	•		•	•	•				•	
. Structural Cracking	•	•	•	•	•	•	•		•	•	•	
. Inclusions	•		•			•				•		
. Corrosion	•			•	•				•	•		
. Residual Stress						•						
. Thickness Gauge	•	•										
. Heat Treatment/Damage		•										
ALUMINUM												
. Fatigue Cracking	•	•	•		•		•				•	
Structural Cracking	•	•	•	•	•		•		•	•	•	
. Inclusions	•		•							•		
. Corrosion	•	•		•	•				•			
. Residual Stress												
. Thickness Gauging	•	•										
. Heat Damage		•										
TITANIUM												
. Fatigue Cracking	•	•	•		•		•				•	
. Structural Cracking	•	•	•	•	•		•		•	•	•	
. Alpha Segregation							•					
. Corrosion	•			•	•				•	•		
. Residual Stress												
. Thickness Gauging	•	•										
. Heat Damage		•										
. FOD Damage									•			
COMPOSITES/LAMINATE STRUCTURES												
. Debonds	•			•				•		•	•	•
. Delaminations	•			•				•		•	•	•
. Moisture Inclusion			•	•				•				
. Fiber/Matrix Cracking					•							
. Bond Strength	•											
OTHER (PLASTICS, ELASTOMERS PYROTECTICS)												
. Cracking	•		•	•	•					•	•	
. Thickness Gauging	•											
. Voids	•			•				•		•	•	

3. Absorb Fleet Losses - Military operational requirements and associated weapon system sophistication in conjunction with prevailing economic pressures to minimize maintenance expenses creates a precarious situation of air system reliability. Mangement becomes faced with the difficult decision balancing the total cost of inspection against the potential cost of failure of an aircraft in flight. Establishing this trade-off relationship prescribes an "acceptable" loss rate which must then be absorbed.

It is this trade-off relationship to which the quest for improved NDE methods is directed.

G. POSSIBLE COST EFFECTIVENESS OF NDE PROCEDURES BASED ON A FOUR YEAR IN-SERVICE FAILURE ANALYSIS. To establish the cost effectiveness of non-destructive evaluation, a computer printout of strike aircraft accident reports for the time frame of January 1972 to January 1976 was obtained from the Naval Safety Center, Norfolk, Virginia. An analysis of this readout was conducted to establish the type of loss category. Only type "A" accidents (which constitute total loss of aircraft) were used for the tabulation of the derived values. These type "A" failures were studied to determine what aircraft models and aircraft sub-systems failed. During the four year period covered by the computer readout, a total of 270 type "A" failures were recorded. Of this number, 51 were failures avoidable via non-destructive evaluation procedures. The actual by cost proportion of accidents avoidable via non-destructive evaluation is 43%. By taking 43% of the total cost of category "A" accidents, one obtains a possible savings of $216,000,000.00. The following computations demonstrate the method used to arrive at these figures.

Tabulation of All Accidents.

Total number of class "A" accidents	-	270
Total number of NDE applicable accidents	-	51

CLASSIFICATION	COST	%
Undetermined Causes	$228,327,000	45.4
Maintenance Errors	55,069,000	11.0
No narrative Description	47,900,000	9.6
Flight Crew Errors	39,383,000	7.8
Not Conducive for NDE	35,473,000	7.1
Compatible for NDE	96,343,000	19.1
TOTAL	$502,495,000	100.0

To derive the actual proportion compatible for NDE, only the clearly defined areas are valid, therefore the categories of "undetermined causes" and "no narrative description" are excluded to find the by cost breakdown.

$$\frac{19.1}{100 - (45.4 + 9.6)} = \text{Actual proportion of defined areas} = 43\%$$

This figure of 43% equates to a total dollar sum of $216,000,000.00 that could have been saved by a proper NDE program during the evaluation period. The percentage figure is shown on the following graph to demonstrate the significance of these savings, Figure 9.

A further breakdown of the category "A" accidents avoidable by NDE attributable to the various sub-systems of the aircraft and also the cost attributable to the various aircraft models is provided in Figures 10, 11 and 12.

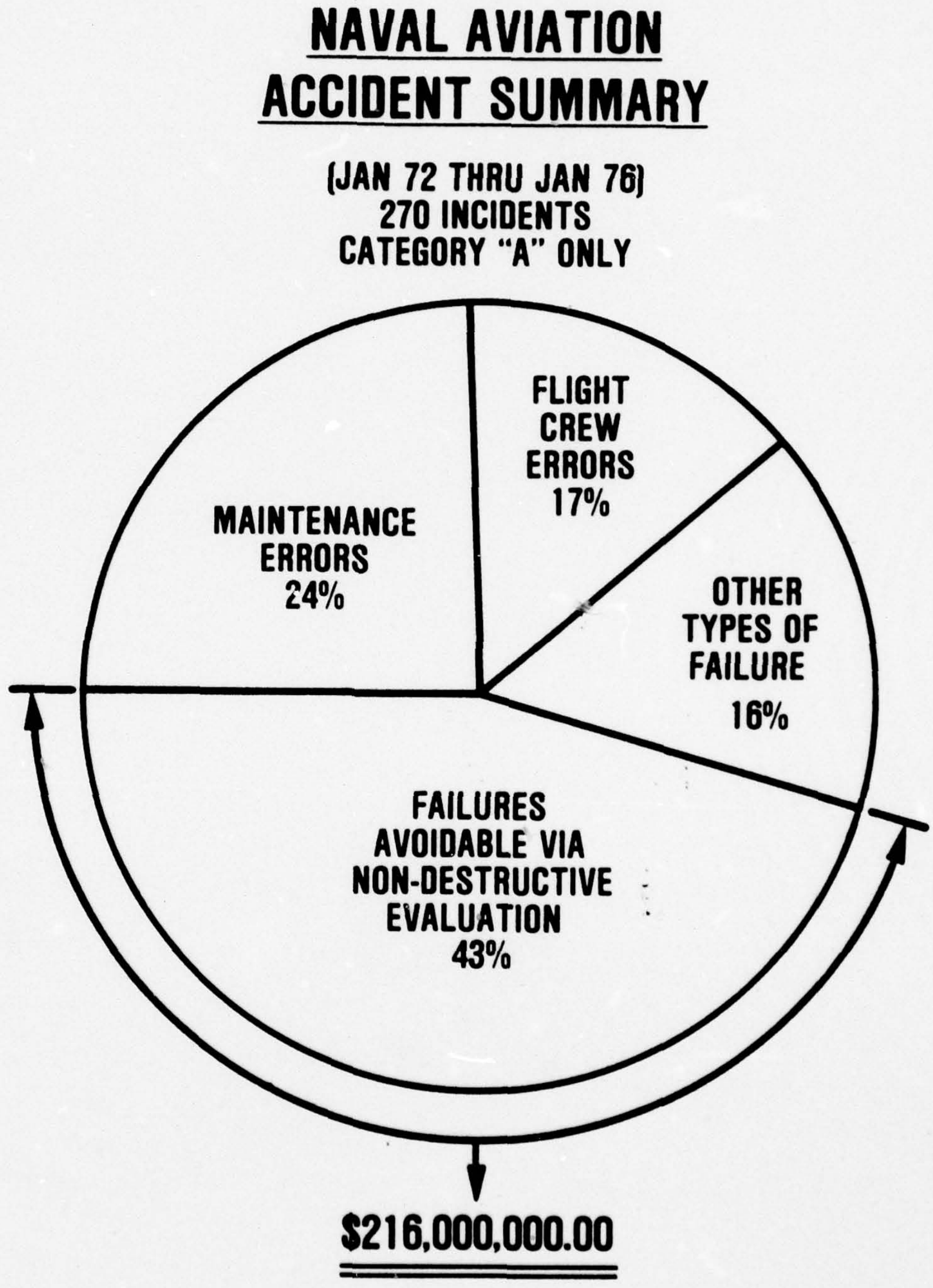


Figure 9. NAVAL AVIATION ACCIDENT SUMMARY

SUB-SYSTEMS		COST
Power Plant		$41,465,000
Air Frame		37,361,000
Helicopter Rotors		6,245,000
Landing Gear		4,618,000
Electrical System		2,510,000
Tires		1,817,000
Hydraulic System		1,286,000
Seat		1,041,000
	TOTAL	$96,343,000

AIRCRAFT		
A7		$28,185,000
F4		22,435,000
RA-5		13,338,000
A-4		10,821,000
C-2		3,821,000
A-6		3,712,000
CH-53		3,214,000
A-3		3,121,000
F-8		2,192,000
H-2		1,564,000
CH-46		1,467,000
C-118		1,286,000
TS-2		623,000
TH-1		386,000
T-28		142,000
	TOTAL	$96,343,000

Figure 10. NDE TABULATION

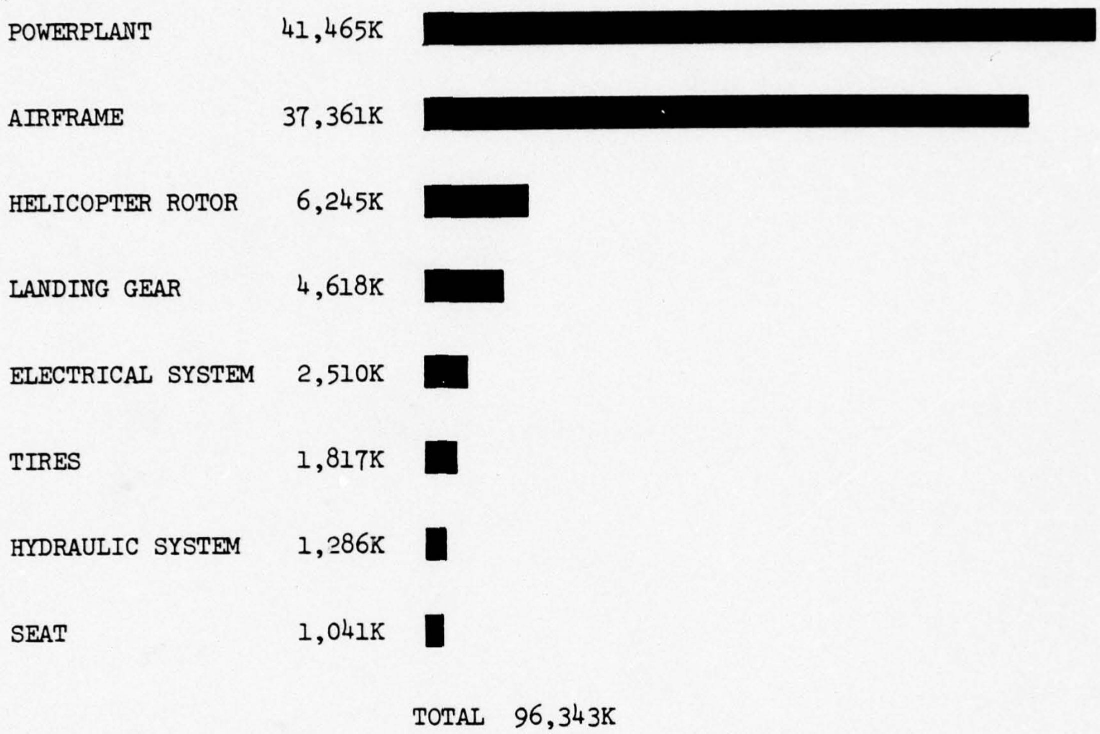


Figure 11. COST OF FAILURES BY SUBSYSTEMS

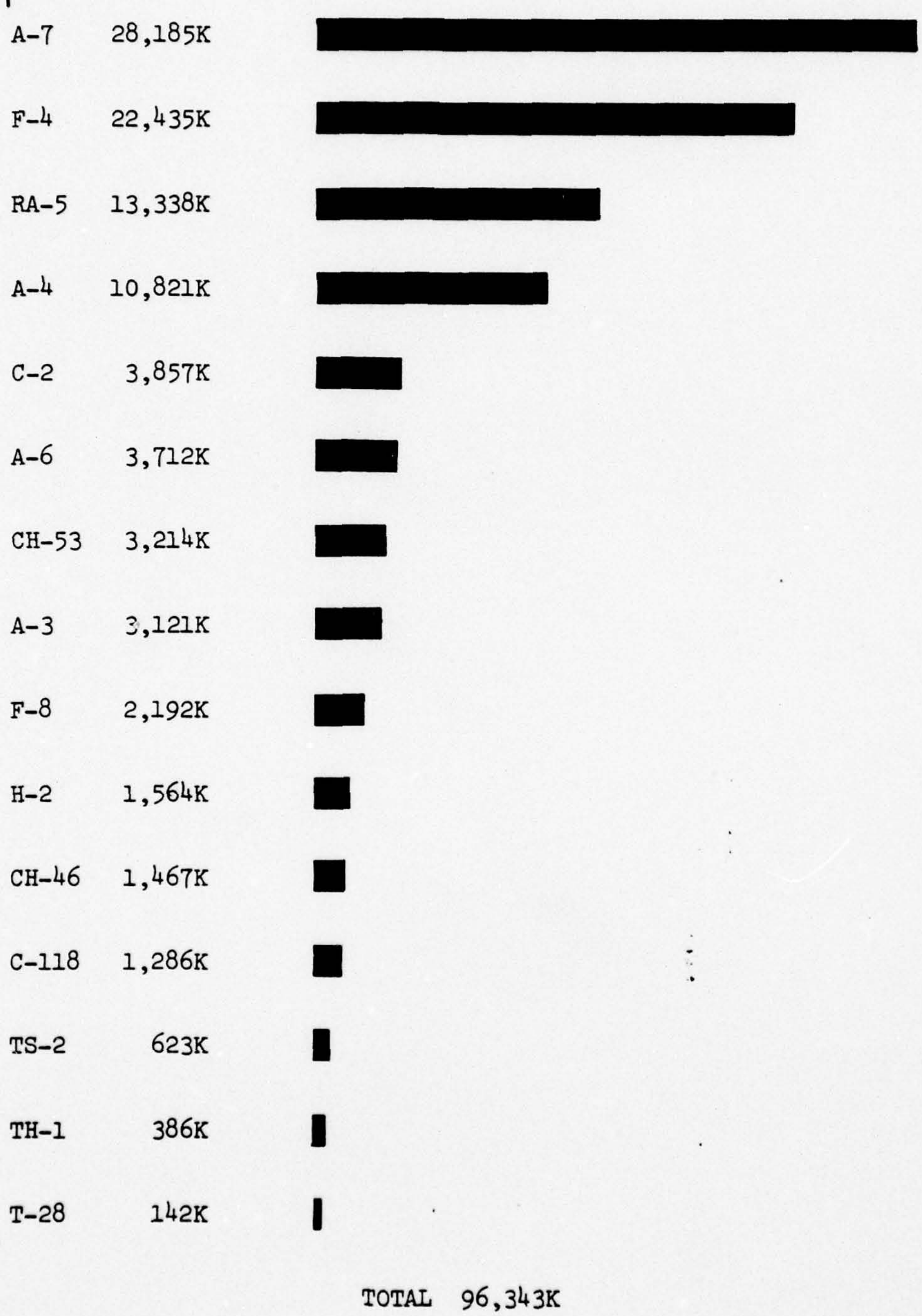


Figure 12. COST OF FAILURES BY AIRCRAFT

VII. RECOMMENDATIONS

A. NDE PERSONNEL RECOMMENDATIONS. Limited investigation within the intermediate and organizational maintenance levels give rise to a number of recommendations regarding Navy NDE personnel.

1. Organizational Level. Limited NDE capability exists at this level and for justified reasons. The largest single problem here is a lack of awareness, not a lack of capability.

It is recommended that maintenance officers and other appropriate "O" level personnel be provided with NDE familiarization films to explain the usefulness and potential pay offs associated with the proper application of NDE. While a limited number of inspections are documented in the format of Bulletins and Maintenance Requirement Cards (MRCs), "on-sight" requirements - those inspections which should be generated during normal operations - often go unrecognized because maintenance personnel are unaware of resident NDE capabilities.

2. Intermediate Level.

a. Provide a minimum (14 weeks DOD NDI School, Chanute AFB, Il.) training program, for all NDE technicians practicing at the intermediate level.

b. Although there currently exists a secondary Naval Enlisted Classification (NEC) rating, AM 7225 Aircraft Structural Nondestructive Inspector (which falls under the primary NEC AMS-72S9 Aviation Structural Mechanic), establish the Nondestructive Inspector as a primary NEC so that individuals are permitted to fully develop and maintain their required skills.

c. Provide advancement potential in order to attract and retain competent individuals.

d. Conduct a statistically based survey to evaluate the overall effectiveness of the Navy NDE system.

It has long been realized that the NDE technician is an integral part of any NDE operation within the Naval Aviation maintenance environment. Despite this realization, little has been done to characterize the effectiveness and reliability of the non-destructive evaluation system, consisting of both hardware elements (i.e., ultrasonics, eddy-current, etc.) and the NDE technician.

If the usefulness of NDE is to be expanded to promote extended operational cycles between depot level overhaul and "on condition" maintenance during that operational cycle, a definitive measure of the NDE capability of both equipment and personnel will have to be established. Further amplification of NDE personnel related factors is presented in Appendix B.

B. RECOMMENDED PROGRAM APPROACHES. This section describes the recommended NDE program options available. They are based on an analysis of the projected technology offerings along with an assessment of current and projected aircraft inspection requirements. These in conjunction with program priorities established in Section VI and available program resources will define a course of prescribed NDE systems development.

TECHNOLOGY AREA: ULTRASONICS

TASK NO. 1-A1 - SIGNAL ANALYSIS/PROCESSING TO IMPROVE INSPECTION CAPABILITY

PROGRAM TASK DESCRIPTION:

Presently, ultrasonic signal interpretation by the operator is the key to successful ultrasonic inspections. Unfortunately, adequate interpretation skills are not universally brought to bear on inspection tasks. This study/evaluation will investigate the potential of utilizing signal data other than amplitude such as frequency content and other pertinent factors to enhance ultrasonic inspection equipment capability. Improved display systems, go-no-go programming signal processing requirements would be addressed.

APPROACH ELEMENTS:

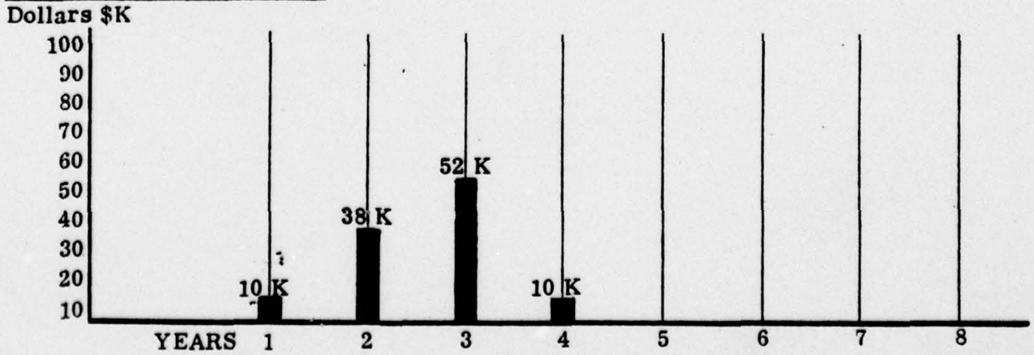
1. Classify defects and flaws which are best suited to ultrasonic techniques. This will be accomplished by reviewing airframe and engine bulletins, aircraft failure reports, MEA (Maintenance Engineering Analyses) and classical text book cases of ultrasonic inspection.

2. Define ultrasonic schemes which could be employed for evaluating material defects. Signal processing requirements, transducer characteristics, output display options and other related parameters would be assessed and stipulated.

3. Develop inspection algorithms which can be utilized with appropriate hardware systems to conduct material defect identification and evaluation. The algorithms would be a function of the critical parameters addressed in part (2) above.

4. Implement computer based breadboard system capable of processing the necessary inspection algorithms.

FUNDING REQUIREMENTS:

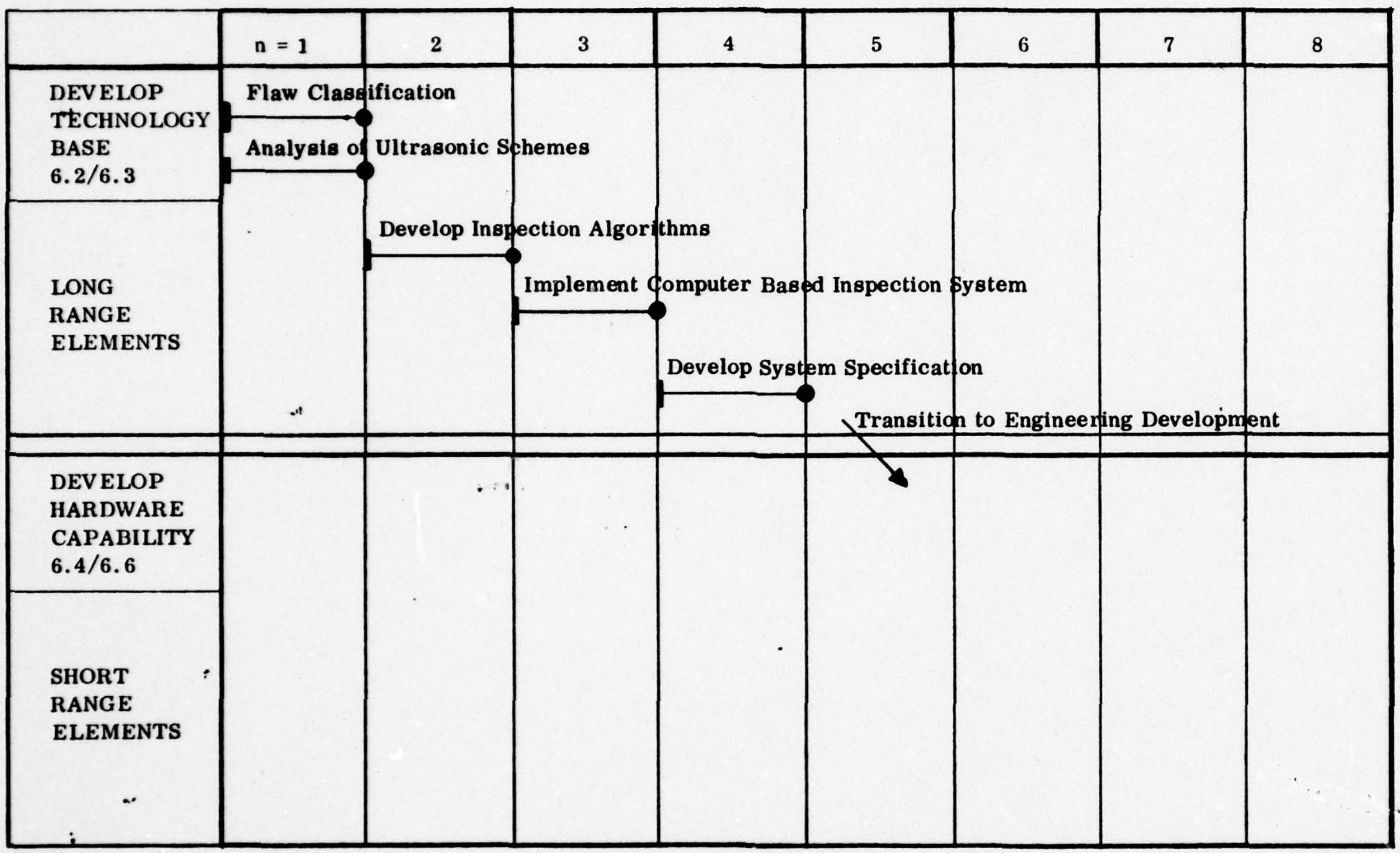


MILESTONE SUMMARY

TASK NO. 1-A1

TECHNOLOGY AREA: ULTRASONICS (SIGNAL ANALYSIS)

FISCAL YEAR



TECHNOLOGY AREA: ULTRASONICS

TASK NO. 1-A2 - INSPECTION RELIABILITY (ULTRASONICS)

PROGRAM TASK DESCRIPTION:

It has long been realized that the NDE technician is an integral part of any NDE operation within the Naval Aviation maintenance environment. Despite this realization, little has been done to characterize the effectiveness and reliability of the non-destructive evaluation system, consisting of both hardware elements (ultrasonics) and the NDE technician. This task involves a statistically based survey to evaluate non-destructive evaluation capability at the intermediate and organizational levels of maintenance. The outcome will be a definitive baseline from which to effectively expand the usefulness of NDE within the aviation maintenance environment.

APPROACH ELEMENTS:

1. Identify and classify the critical flaws, equipment conditions and system defects which are inspectable with present inventory ultrasonic equipment.

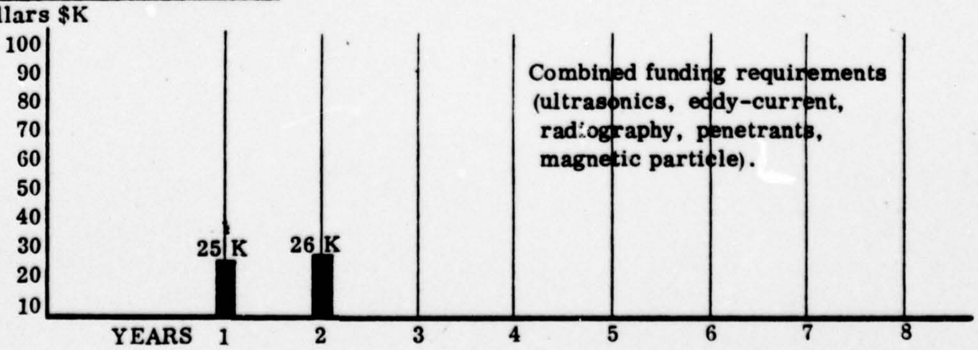
2. Acquire and/or develop selected defect samples representative of the above (1) inspection situations.

3. Establish statistical test requirements and appropriate survey schedule.

4. Implement survey and construct data analysis model.

FUNDING REQUIREMENTS:

Dollars $K



MILESTONE SUMMARY

TASK NO. 1-A2

TECHNOLOGY AREA: ULTRASONICS (INSPECTION RELIABILITY)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Identify and Classify Critical Flaws - Acquire/Develop Defect Samples - Establish Statistical Test Requirements							
LONG RANGE ELEMENTS		- Conduct Survey - Construct Data Analysis Model						
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: ULTRASONICS

TASK NO. 1-A3 - ULTRASONIC INSPECTION STANDARDS

PROGRAM TASK DESCRIPTION:

In the field of ultrasonic inspection, Standards play a significant role in control of inspection integrity. Unfortunately, "similar" standards often times do not yield similar responses. The need exists to develop high quality standards which are more representative of aircraft materials and their defects.

APPROACH ELEMENTS:

1. Analysis of maintenance documentation to establish defect limits and equipment "on condition" standards.

2. Evaluate existing standards available for use at the intermediate and organizational levels of maintenance.

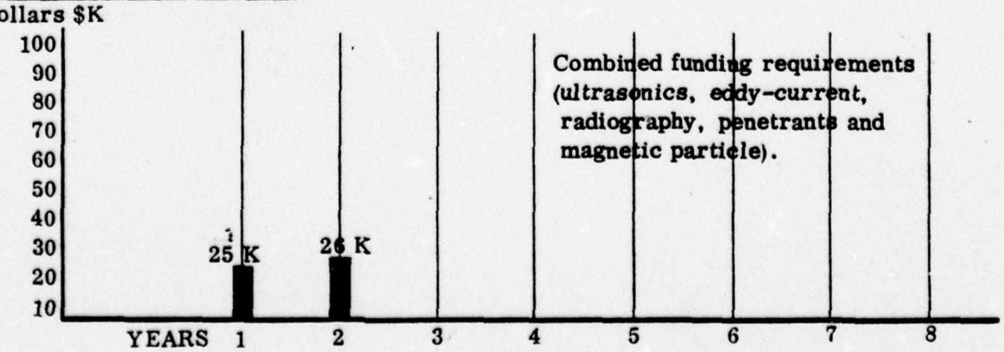
3. Identify standard deficiencies within the Naval aviation maintenance environment.

4. Canvass other sources of applicable standards (Air Force, NASA, industrial activities, etc.) to address deficiencies.

NOTE: Work has been done in this area by the Air Force (AFML-TR-77-40). This task should be implemented only to the extent that NBS work needs to be supplemented for NAVAIR requirements.

FUNDING REQUIREMENTS:

Dollars $K



MILESTONE SUMMARY

TASK NO. 1-A3

TECHNOLOGY AREA: ULTRASONICS (STANDARDS)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Conduct Maintenance Documentation Study to Establish Defect Limits - Correlate Intermediate and Organizational Level Standard Requirements							
LONG RANGE ELEMENTS	Evaluation of Existing Standards	- Classification of Standard Deficiencies - Investigation of Alternatives	Recommend Appropriate Inventory Standard Additions					
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: EDDY-CURRENT

TASK NO. 2-A1 - ADVANCED CONCEPT EDDY-CURRENT INSPECTION SYSTEM

PROGRAM TASK DESCRIPTION:

Eddy-current inspection systems are being called upon to perform fleet inspections which border on, if not exceed, their demonstrated capability (i.e., TF-30 fan blade inspection).

In order to resolve this condition, advanced concept eddy-current systems such as multi-frequency, pulsed signal and integrated signal processing would be investigated to improve the sensitivity and reliability of eddy-current inspection equipment.

APPROACH ELEMENTS:

1. Classify defect and flaws which are best suited to eddy-current techniques. This will be accomplished by reviewing airframe and engine bulletins, aircraft failure reports, MEA (Maintenance Engineering Analyses) and classical text book cases of eddy-current inspection.

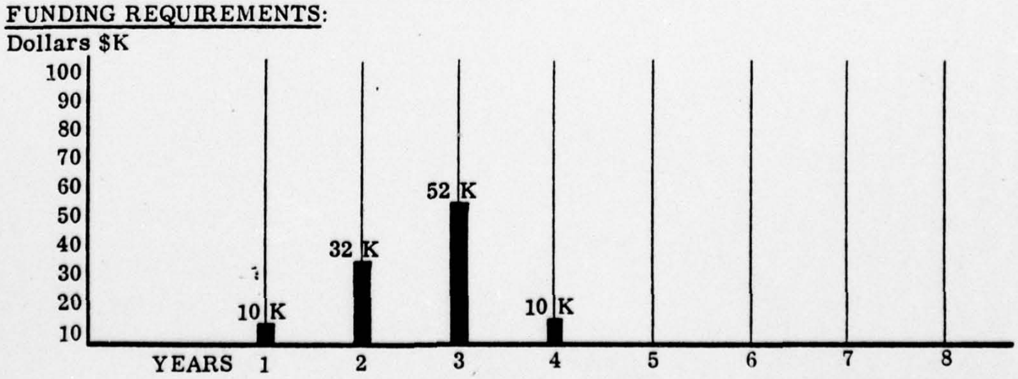
2. Define eddy-current schemes which could be employed for evaluating material defects. Signal frequency combinations, signal parameters and processing options, probe requirements and output display modes would be analyzed and evaluated. The output of this task will be system parameters which will form the basis for the next generation of fleet eddy-current equipment.

3. Demonstrate a breadboard model which will perform the required eddy-current inspection functions in order to establish confident hardware realization requirements.

4. Develop a prototype specification which would be utilized for procuring a "field" evaluation unit.

NOTE: Some work has been done in the area of Multi-Frequency specifically for detecting cracks under fasteners by the Air Force (AFML-TR-76-209).

FUNDING REQUIREMENTS:

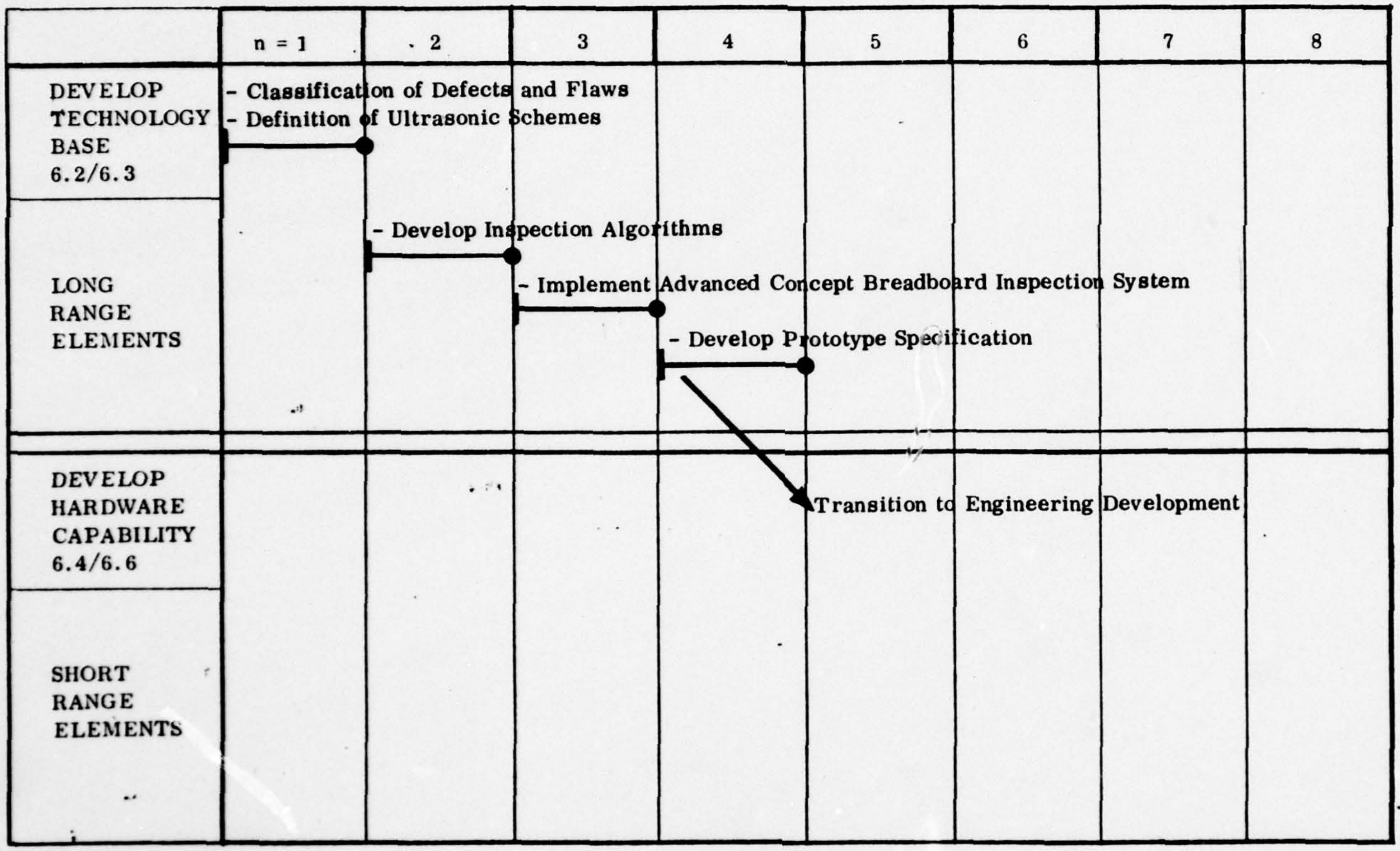


MILESTONE SUMMARY

TASK NO. 2-A1

TECHNOLOGY AREA: EDDY-CURRENT (ADVANCED CONCEPT SYSTEM)

FISCAL YEAR



TECHNOLOGY AREA: EDDY-CURRENT

TASK NO. 2-A2 - INVESTIGATION OF STANDARDS

PROGRAM TASK DESCRIPTION:

In the field of ultrasonic inspection, standards play a significant role in control of inspection integrity. Unfortunately, "similar" standards often times do not yield similar responses. The need exists to develop high quality standards which are more representative of aircraft materials and their defects.

APPROACH ELEMENTS:

1. Analysis of maintenance documentation to establish defect limits and equipment "on condition" standards.

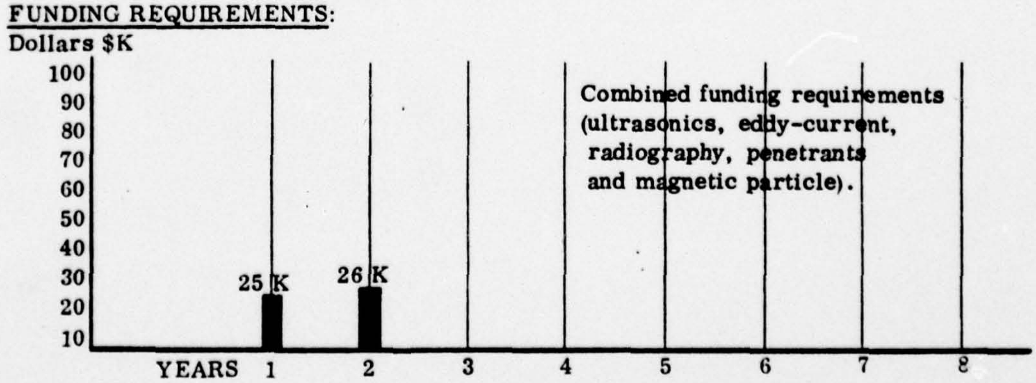
2. Evaluate existing standards available for use at the intermediate and organizational levels of maintenance.

3. Identify eddy-current standard deficiencies within the Naval aviation maintenance environment.

4. Canvass other sources of applicable standards (Air Force, NASA, industrial activities, etc.) to address deficiencies.

NOTE: This would be implemented only to the extent that NBS work needs to be supplemented for NAVAIR requirements.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 2-A2

TECHNOLOGY AREA: EDDY-CURRENT (STANDARDS INVESTIGATION)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Conduct Maintenance Documentation Study to Establish Defect Limits - Coordinate Intermediate and Organizational Level Standard Requirements							
LONG RANGE ELEMENTS	- Evaluation of Existing Standards	- Classification of Standard Deficiencies - Investigation of Alternatives	(Recommend Appropriate Inventory Standard Additions)					
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: EDDY-CURRENT

TASK NO. 2-A3 (INSPECTION RELIABILITY)

PROGRAM TASK DESCRIPTION:

It has long been realized that the NDE technician is an integral part of any NDE operation within the Naval Aviation maintenance environment. Despite this realization, little has been done to characterize the effectiveness and reliability of the non-destructive evaluation system consisting of both hardware elements (eddy-current) and the NDE technician. This task involves a statistically based survey to evaluate non-destructive evaluation capability at the intermediate and organizational levels of maintenance. The outcome would be a definitive baseline from which to effectively expand the usefulness of NDE within the aviation maintenance environment.

APPROACH ELEMENTS:

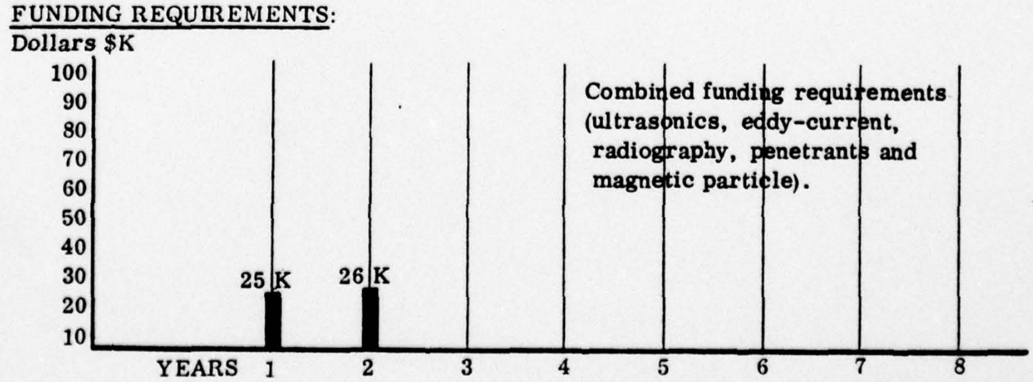
1. Identify and classify the critical flaws, equipment conditions and system defects which are inspectable with present inventory eddy-current equipment.

2. Acquire and/or develop selected defect samples representative of the above (1) inspection situations.

3. Establish statistical test requirements and appropriate survey schedule.

4. Implement survey and construct data analysis model.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 2-A3

TECHNOLOGY AREA: EDDY-CURRENT (INSPECTION RELIABILITY)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Identify and Classify Critical Flaws - Acquire/Develop Defect Samples - Establish Statistical Test Requirements							
LONG RANGE ELEMENTS		- Conduct Survey - Conduct Data Analysis Model						
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: X-RADIOGRAPHY

TASK NO. 3-A1 - ISOTOPE RADIOGRAPHY

PROGRAM TASK DESCRIPTION:

This task would investigate the technology of isotope radiography, a technique successfully applied by the airlines to provide internal engine inspection without resorting to engine disassembly. A radioactive isotope is utilized as a source of radiation in lieu of a conventional x-ray tube. The basic system consists of an enclosure for housing the isotope "pill" when not in use and a suitable remote control device for transporting the pill to the inspection station. Suitability for Naval aviation maintenance requirements would be assessed and evaluated.

APPROACH ELEMENTS:

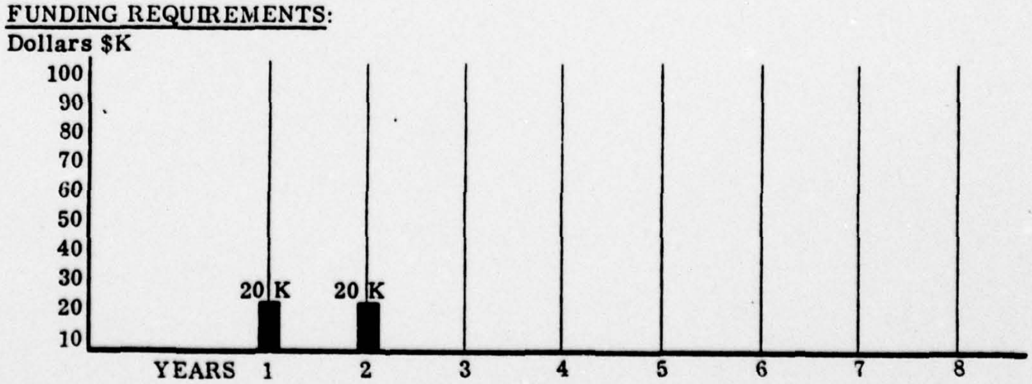
1. Analyze airline isotope inspection procedures to determine inspection capability.

2. Review and assess Naval aviation maintenance procedures, particularly engine maintenance actions, regarding the potential for isotope system radiography.

3. Conduct feasibility demonstrations for selected characteristic inspection tasks.

4. Analyze safety criteria, associated with the implementation of isotope radiography.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 3-A1

TECHNOLOGY AREA: X-RADIOGRAPHY

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Analyze Airline Inspection Procedures (Isotope Radiography) - Review and Assess Appropriate Naval Aviation Maintenance Action/Procedures							
LONG RANGE ELEMENTS		- Conduct Feasibility Demonstrations - Safety Criteria Analysis		Recommend Appropriate Follow On Action				
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: X-RADIOGRAPHY

TASK NO. 3-A2 - INSPECTION RELIABILITY

PROGRAM TASK DESCRIPTION:

It has long been realized that the NDE technician is an integral part of any NDE operation within the Naval aviation maintenance environment. Despite this realization, little has been done to characterize the effectiveness and reliability of the non-destructive evaluation system consisting of both hardware elements (x-ray) and the NDE technician. This task involves a statistically based survey to evaluate non-destructive evaluation capability at the intermediate and organizational levels of maintenance. The outcome would be a definitive baseline from which to effectively expand the usefulness of NDE within the aviation maintenance environment.

APPROACH ELEMENTS:

1. Identify and classify the critical flaws, equipment conditions and system defects which are inspectable with present inventory x-ray equipment.

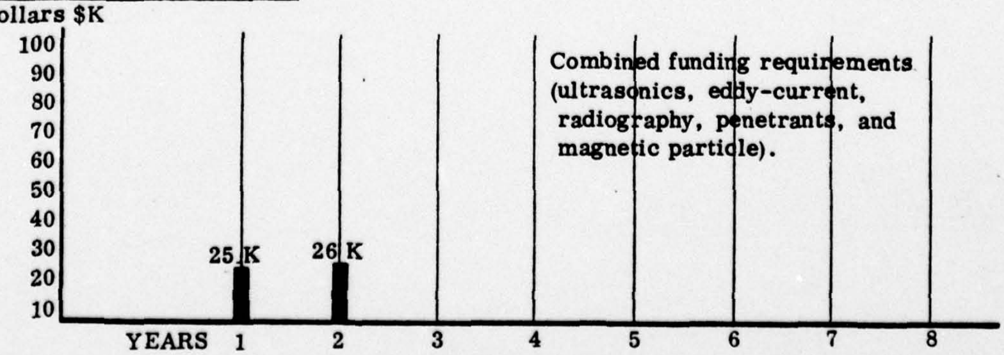
2. Acquire and/or develop selected defect samples representative of the above (1) inspection situations.

3. Establish statistical test requirements and appropriate survey schedule.

4. Implement survey and construct data analysis model.

FUNDING REQUIREMENTS:

Dollars $K



MILESTONE SUMMARY

TASK NO. 3-A2

TECHNOLOGY AREA: X-RADIOGRAPHY (INSPECTION RELIABILITY)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Identify and Classify Critical Flaws - Acquire/Develop Defect Samples - Establish Statistical Test Requirements							
LONG RANGE ELEMENTS		- Conduct Survey - Conduct Data Analysis Model						
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: NEUTRON RADIOGRAPHY

TASK NO. 4-A1

PROGRAM TASK DESCRIPTION:

What has been lacking in the neutron radiography field up till the present has been a convenient source of neutrons which could be utilized in the aviation maintenance environment.

Californium based systems require considerable shielding and they cannot be turned off. The result is a bulky system which requires considerable precaution in using.

Recent advances in the oil exploration field have produced protable neutron generating tubes very much similar to x-ray tubes. The application of these accelerator tubes offers a low-cost, protable N-ray system for routine field inspection of aircraft structural components.

APPROACH ELEMENTS:

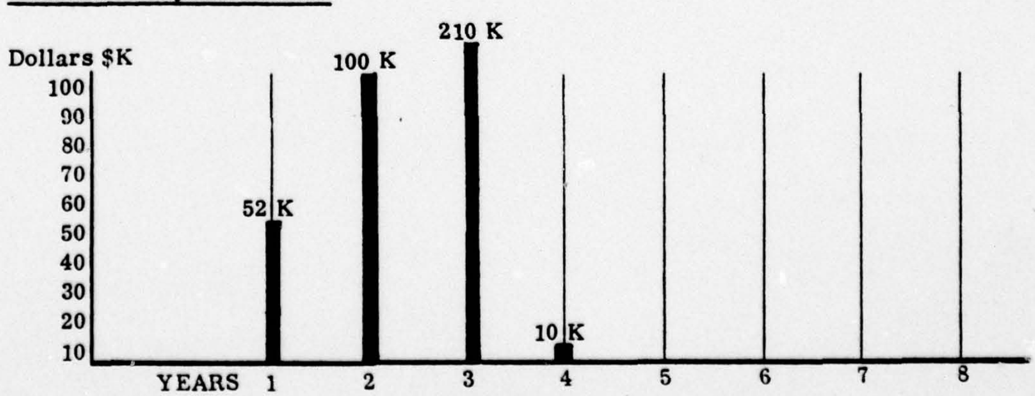
1. Evaluate the feasibility of a low-cost, protable accelerator N-ray system for routine field inspection of aircraft structural components.

2. Design a breadboard accelerator neutron system for field N-ray inspection applications.

3. Fabricate a breadboard demonstration system and evaluate the usefulness of such a system for Navy aircraft inspection requirements.

4. Develop a prototype specification which would be utilized for procuring a "field" evaluation unit.

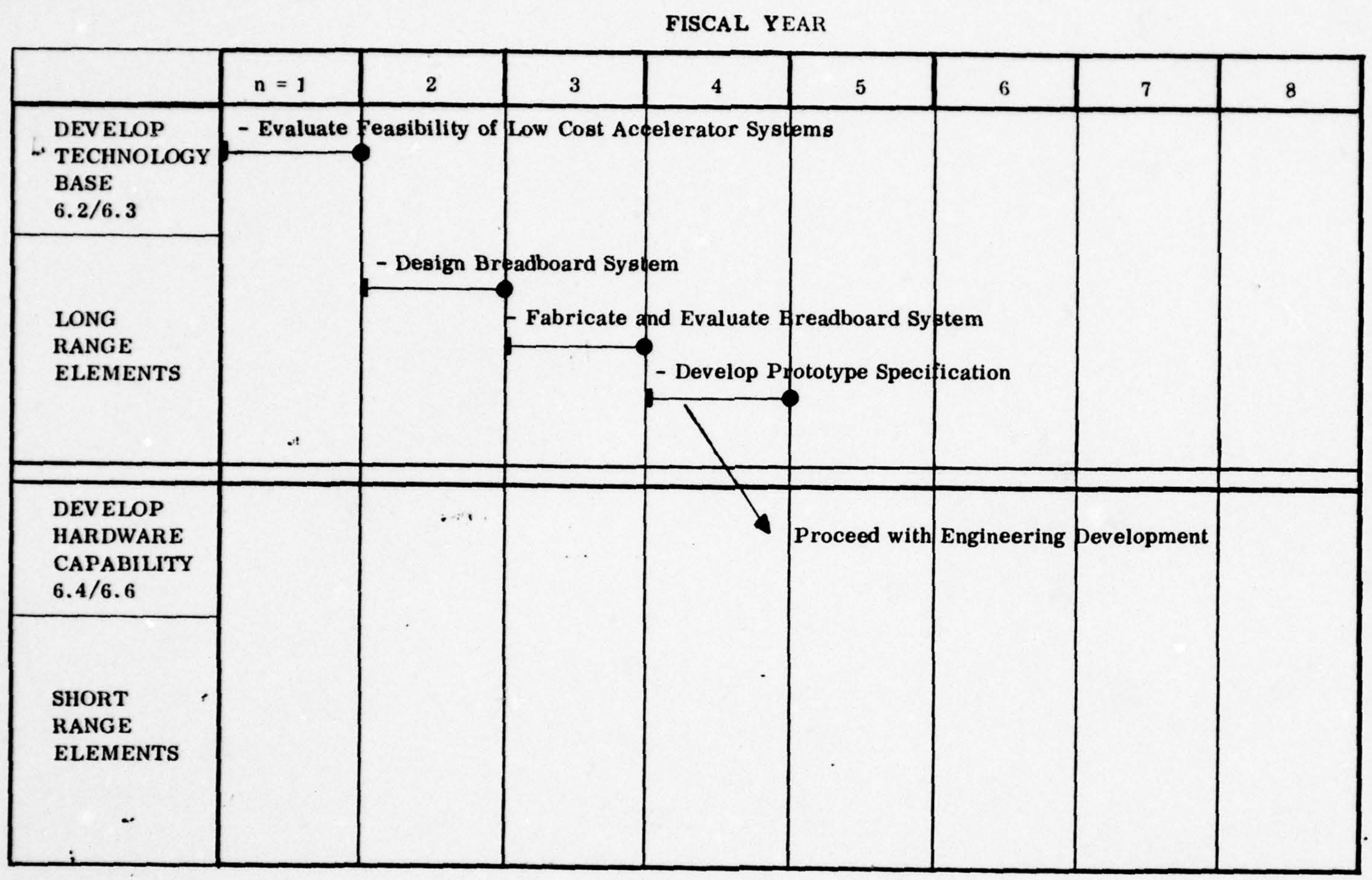
FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 4-A1

TECHNOLOGY AREA: NEUTRON RADIOGRAPHY



TECHNOLOGY AREA: NEUTRON RADIOGRAPHY

TASK NO. 4-A2 - APPLICATION SURVEY

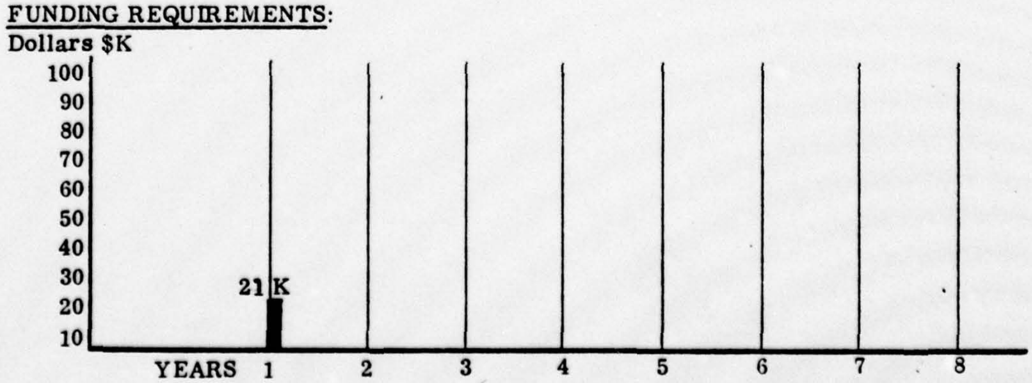
PROGRAM TASK DESCRIPTION:

Neutron radiography is emerging as a versatile cost-saving non-destructive evaluation method for aircraft structures. Numerous applications of neutron radiography to field inspection of aircraft structures have been investigated. A compendium is now required which will indicate the capability and limitations of neutron radiography for effective inspection of specific representative structures.

APPROACH ELEMENTS:

Develop a compendium of Neutron Radiograph applications to field inspection of aircraft structures. This investigation will provide an indication of the scope and potential usefulness of N-ray techniques/systems and also serve as an aid to interpretation of future neutron radiographic results.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 4-A2

TECHNOLOGY AREA: NEUTRON RADIOGRAPHY (APPLICATION SURVEY)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Develop Neutron Radiography Compendium							
LONG RANGE ELEMENTS		Input Into Equipment Development Program						
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

<u>TECHNOLOGY AREA</u>: ACOUSTIC EMISSION

<u>TASK NO.</u> 5-A1 - SIGNAL CHARACTERIZATION SURVEY

<u>PROGRAM TASK DESCRIPTION</u>:

Acoustic emission is presently experiencing a rapid growth in applicational developments. In order to establish equipment performance requirements for appropriate aircraft inspection tasks via acoustic emission, an application survey would be conducted. Acoustic emission signature characterization would provide definative signal processing goals for follow on prototype equipment development programs.

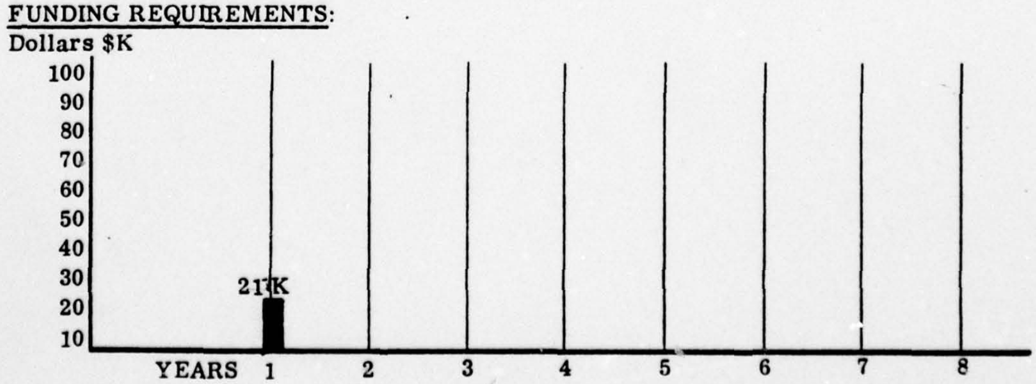
<u>APPROACH ELEMENTS</u>:

1. Establish aircraft inspection tasks applicable to acoustic emission methods.

2. Investigate acoustic emission signal characteristics to establish criteria for signature classification.

3. Summarize equipment signal processing requirements for feasible aircraft inspection.

<u>FUNDING REQUIREMENTS</u>:



MILESTONE SUMMARY

TASK NO. 5-A1

TECHNOLOGY AREA: ACOUSTIC EMISSION (SIGNAL CHARACTERIZATION)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Investigate Aircraft Inspection Tasks - Characterize Acoustic Emission Signatures							
LONG RANGE ELEMENTS		Input into Equipment Development Program						
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: ACOUSTIC EMISSION

TASK NO. 5-A2 - PORTABLE ACOUSTIC EMISSION SYSTEMS

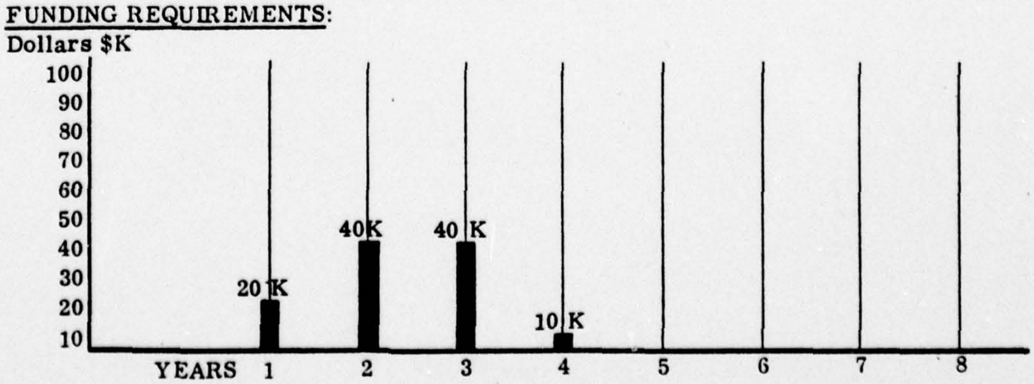
PROGRAM TASK DESCRIPTION:

Acoustic emission is being successfully applied to many inspection tasks with elaborate, generally fixed base equipment systems. This task would investigate the feasibility of developing a portable acoustic emission monitoring capability to be utilized at the intermediate and organizational levels of maintenance.

APPROACH ELEMENTS:

1. Feasibility study for portable acoustic emission systems.
2. Conduct investigation to define optimal system stimuli.
3. Develop and evaluate "breadboard acoustic emission inspection system".
4. Develop prototype specification.

FUNDING REQUIREMENTS:

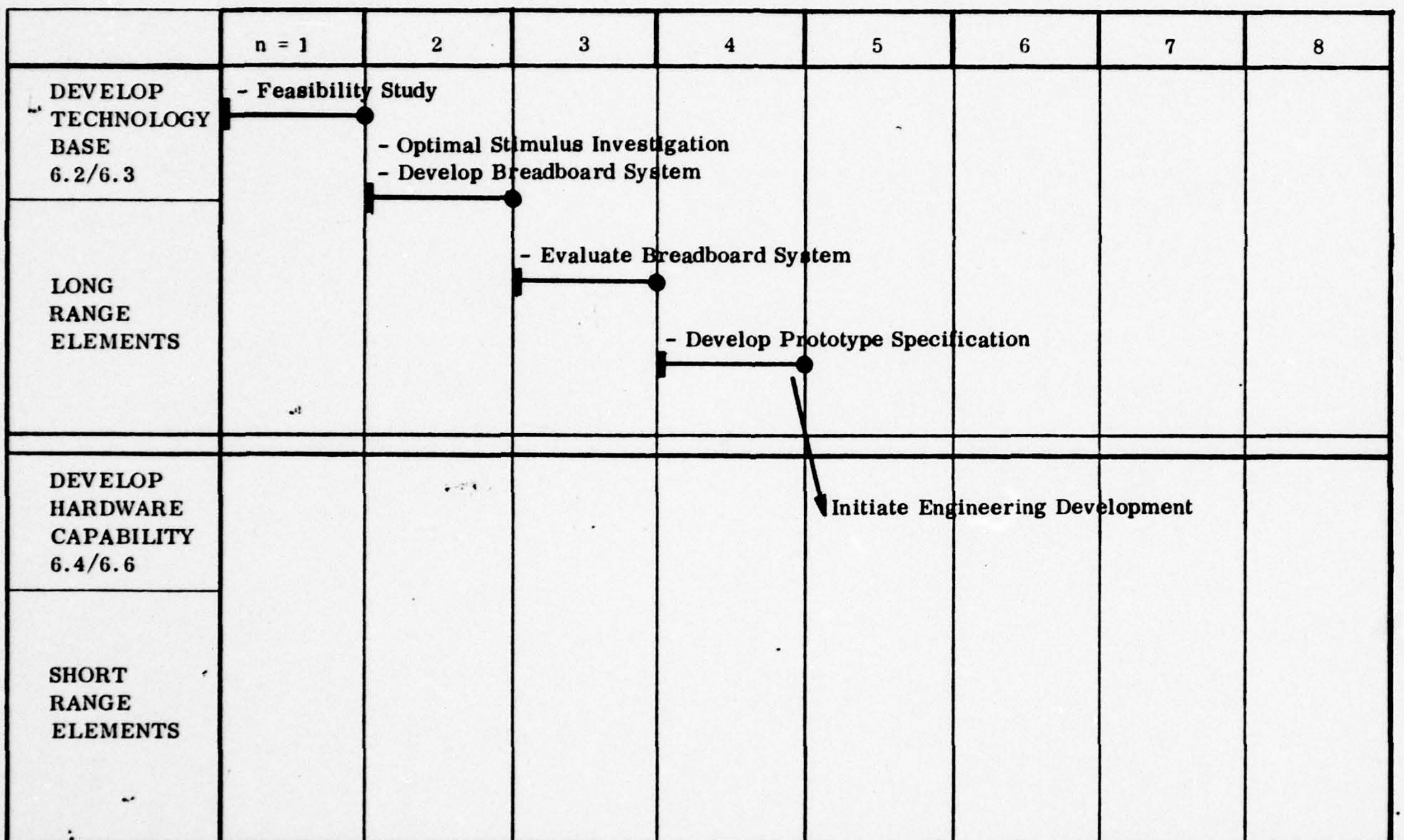


MILESTONE SUMMARY

TASK NO. 5-A2

TECHNOLOGY AREA: ACOUSTIC EMISSION (PORTABLE ACOUSTIC EMISSION SYSTEMS)

FISCAL YEAR



TECHNOLOGY AREA: MAGNETICS

TASK NO. 6-A1 - BARKHAUSEN REFINEMENT

PROGRAM TASK DESCRIPTION:

The usefulness of the Barkhausen technique for measuring residual stress in ferromagnetic materials has been limited as a result of insufficient magnetic field strength control and signal processing deficiencies. This task would address these two critical areas in order to improve the sensitivity and repeatability of Barkhausen residual stress measurement equipment.

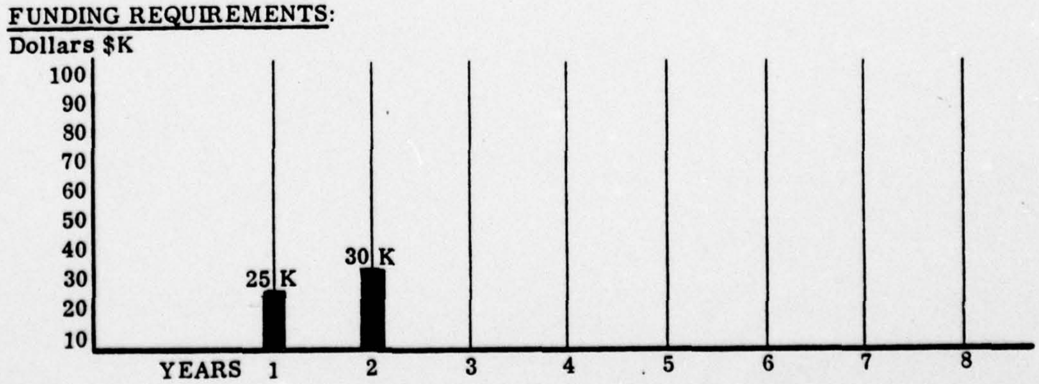
APPROACH ELEMENTS:

1. Investigate incorporation of feedback circuit control to minimize magnetic field variations caused by component geometry variations and material factors.

2. Investigate lift-off compensation circuitry.

3. Investigate noise pulse analysis/signal processing to improve system sensitivity and reliability.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 6-A1

TECHNOLOGY AREA: MAGNETICS (BARKHAUSEN REFINEMENT)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Investigate Incorporation of Feedback Control - Investigate Lift-off Compensation							
LONG RANGE ELEMENTS		- Investigate Noise Pulse Analysis						
DEVELOP HARDWARE CAPABILITY 6.4/6.6			Recommended Prototype Alterations					
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: MAGNETICS

TASK NO. 6-A2 - INSPECTION RELIABILITY

PROGRAM TASK DESCRIPTION:

It has long been realized that the NDE technician is an integral part of any NDE operation within the Naval aviation maintenance environment. Despite this realization, little has been done to characterize the effectiveness and reliability of the non-destructive evaluation system consisting of both hardware elements (magnetic inspection) and the NDE technician. This task involves a statistically based survey to evaluate non-destructive evaluation capability at the intermediate and organizational levels of maintenance. The outcome would be a definitive baseline from which to effectively expand the usefulness of NDE within the aviation maintenance environment.

APPROACH ELEMENTS:

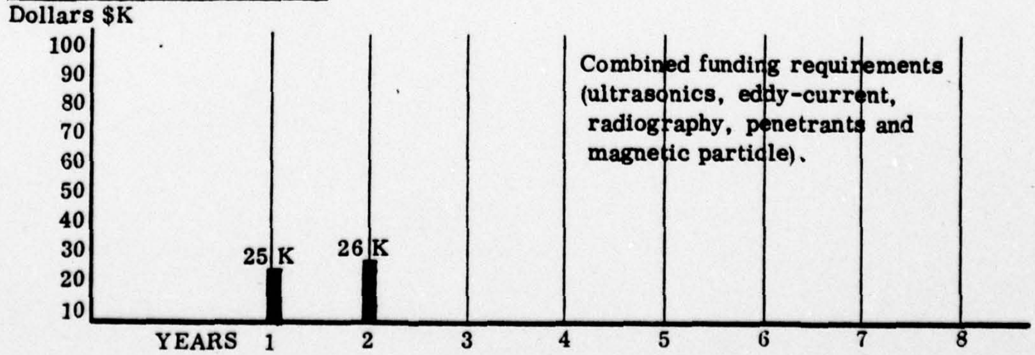
1. Identify and classify the critical flaws equipment conditions and system defects which are inspectable with present inventory magnetic inspection equipment.

2. Acquire and/or develop selected defect samples representative of the above (1) inspection situations.

3. Establish statistical test requirements and appropriate survey schedule.

4. Implement survey and construct data analysis model.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY — TASK NO. 6-A2

TECHNOLOGY AREA: MAGNETICS - INSPECTION RELIABILITY

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Identify and Classify Critical Flaws - Acquire/Develop Defect Samples - Establish Statistical Test Requirements							
LONG RANGE ELEMENTS		- Conduct Survey - Conduct Data Analysis Model						
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: PENETRANTS

TASK NO. 7-A1 - CHEMICAL AMPLIFICATION

PROGRAM TASK DESCRIPTION:

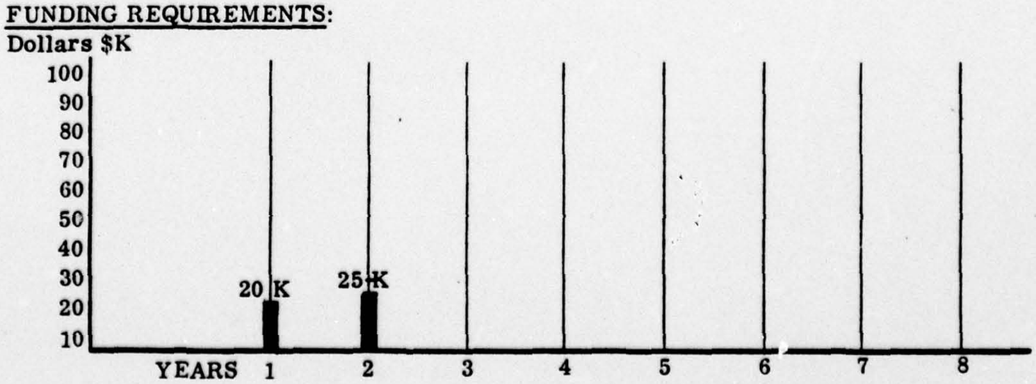
The difficulty with penetrant inspection is that when the crack size is very small, there is often not enough penetrant in the crack to produce a visible reaction in the developer. This task would address this problem by investigating chemical amplifying polymerization methods which have the potential of 10X crack size image enlargement.

APPROACH ELEMENTS:

1. Conduct a feasibility study to investigate catalysts, solvents, polymers, dyes, wetting agents and heating and illumination conditions.

2. Evaluate combinations exhibiting optimal performance against current methods in use to quantify improved crack amplification.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 7-A1

TECHNOLOGY AREA: PENETRANTS (CHEMICAL AMPLIFICATION)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Conduct Feasibility Study of Chemical Amplification							
LONG RANGE ELEMENTS		- Evaluate Optimal Combinations		Recommend Appropriate Field Method Alterations				
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: PENETRANTS

TASK NO: 7-A2 - KRYPTON EMISSION TECHNIQUE

PROGRAM TASK DESCRIPTION:

This task would investigate the application of radioactive penetrants (KET - Krypton Emission Technique) for the inspection of aircraft components. In the aviation maintenance process, because of limits in defect detection processes, there are untold numbers of parts which have been kept from reuse - not because the parts are known to be bad, but because they cannot be proven to be good. KET offers significant sensitivity improvement which should be investigated.

APPROACH ELEMENTS:

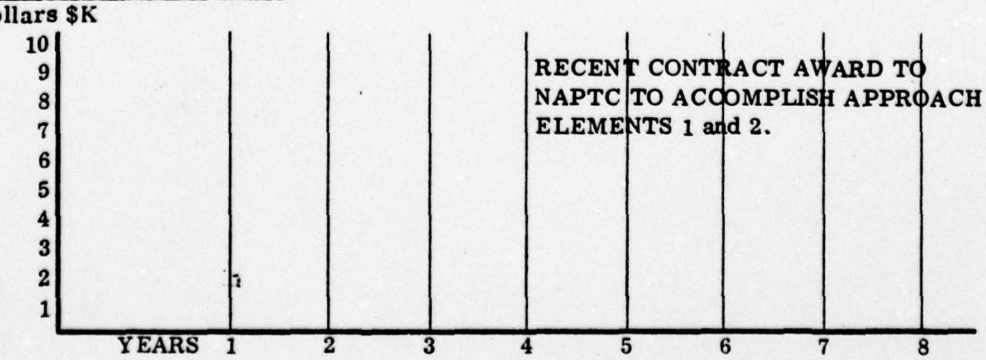
1. Establish a listing of aircraft component inspection requirements to which radioactive penetrant methods could be applied.

2. Conduct laboratory investigations to establish the available inspection sensitivity and reliability.

3. Evaluate cost, safety and inspection efficiency factors associated with radioactive penetrant systems.

FUNDING REQUIREMENTS:

Dollars $K



MILESTONE SUMMARY

TASK NO. 7-A2

TECHNOLOGY AREA: PENETRANTS (KRYPTON EMISSION TECHNIQUE)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Establish Listing of Inspection Requirements - Conduct Laboratory Component Inspections							
LONG RANGE ELEMENTS		- Evaluate Cost, Safety and Inspection Efficiency Factors	Develop Prototype Specification					
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: PENETRANTS

TASK NO.· 7-A3 - INSPECTION RELIABILITY

PROGRAM TASK DESCRIPTION:

It has long been realized that the NDE technician is an integral part of any NDE operation within the Naval aviation maintenance environment. Despite this realization, little has been done to characterize the effectiveness and reliability of the non-destructive evaluation system consisting of both hardware elements (penetrant systems) and the NDE technician. This task involves a statistically based survey to evaluate non-destructive evaluation capability at the intermediate and organizational levels of maintenance.

APPROACH ELEMENTS:

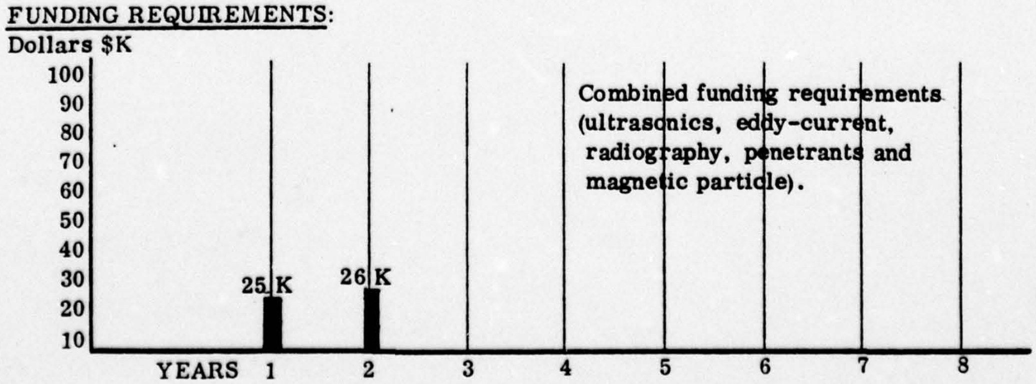
1. Identify and classify the critical flaws equipment conditions and system defects which are inspectable with present inventory penetrant inspection equipment.

2. Acquire and/or develop selected defect samples representative of the above (1) inspection situations.

3. Establish statistical test requirements and appropriate survey schedule.

4. Implement survey and construct data analysis model.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 7-A3

TECHNOLOGY AREA: PENETRANTS (INSPECTION RELIABILITY)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Identify and Classify Critical Flaws - Acquire/Develop Defect Samples - Establish Statistical Test Requirements (n = 1)							
LONG RANGE ELEMENTS		- Conduct Survey - Construct Data Analysis Model (2)						
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: THERMOGRAPHY

TASK NO. 8-A1 - INFRA-RED ENGINE HOT SECTION INSPECTION)

PROGRAM TASK DESCRIPTION:

The inspection of turbine hot section components remains as a difficult yet vitally useful diagnostic requirement.

Fine based overhaul schedules and/or disassemble to inspect operations are recognized as an inefficient approach to required operational reliability. A combined system of infra-red cameras, fiber optic transmission lines and related components would be investigated for real time, flight line engine inspection requirements.

APPROACH ELEMENTS:

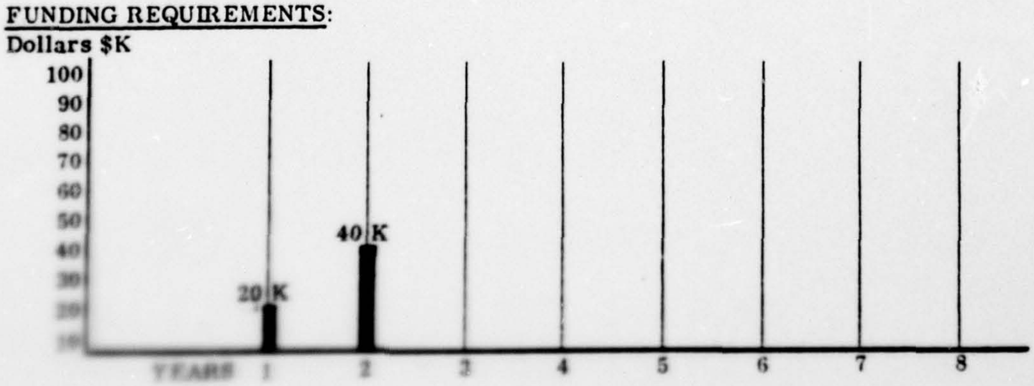
1. Analyze available thermal engine signature data (blades, burners, etc.).

2. Evaluate power plant inventory for borescope accessibility criteria.

3. Conduct engine test stand evaluation of breadboard system.

4. Implement engine disassembly inspection to correlate test data with actual component conditions.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 8-A1

TECHNOLOGY AREA: THERMOGRAPHY (ENGINE HOT SECTION INSPECTION)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Analyze engine Thermal Signature Data - Evaluate Power Plant Inventory (Accessibility Data)							
LONG RANGE ELEMENTS		- Breadboard Test Stand Evaluation - Engine Disassembly Inspection	Develop Prototype Specification					
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: THERMOGRAPHY

TASK NO. 8-A2 - MICROWAVE THERMOGRAPHY

PROGRAM TASK DESCRIPTION:

The application of microwave thermography has been successfully applied to medical diagnosis via subsurface temperature distribution analysis. Other microwave techniques used for aircraft component inspection tasks suggest the possible application of microwave thermography for aircraft non-destructive evaluation, particularly composite material aircraft structures. This task would investigate the feasibility of microwave thermography as it pertains to selected inspection requirements.

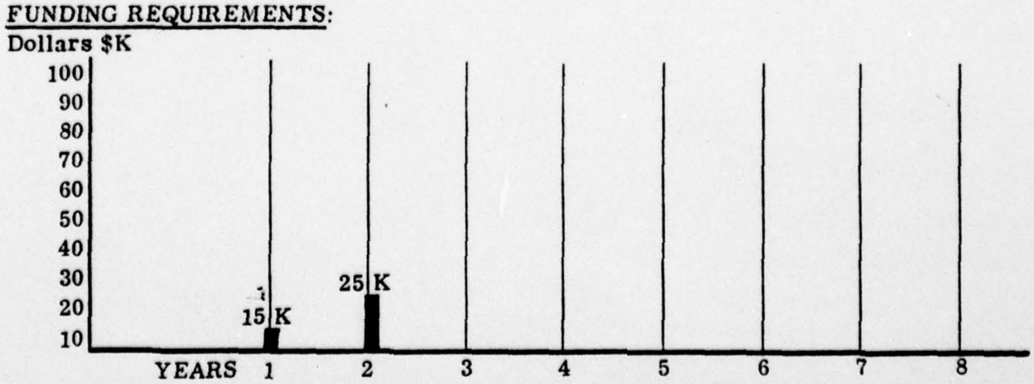
APPROACH ELEMENTS:

1. Analyze characteristic airframe materials/components for microwave transmission/absorption behavior.

2. Investigate appropriate thermal signature stimulation methods.

3. Conduct laboratory experimentation to evaluate inspection feasibility for selected "most probable applications".

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 8-A2

TECHNOLOGY AREA: THERMOGRAPHY (MICROWAVE THERMOGRAPHY)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Analyze Airframe Materials Behavior - Investigate Thermal Signature Stimulation							
LONG RANGE ELEMENTS		- Conduct Lab Feasibility Demonstration	Prototype Development if Appropriate					
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: OPTICAL SYSTEMS

TASK NO. 9-A1 - LOW LIGHT T.V. INSPECTION SYSTEMS

PROGRAM TASK DESCRIPTION:

Developments in high-sensitivity, miniaturized television systems have provided an inspection capability potentially applicable to field inspection requirements. This task would investigate the feasibility of utilizing such devices, and establish the operational effectiveness of television systems vs conventional borescopes.

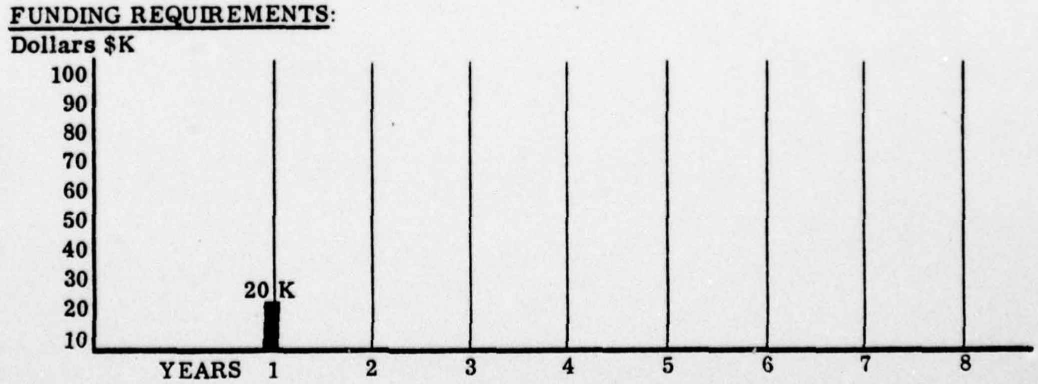
APPROACH ELEMENTS:

1. Evaluate the current "state-of-the-art" in low-light television systems.

2. Analyze the applicational effectiveness and potential field durability of these systems.

3. Comparatively assess the value of T.V. inspection systems vs borescopes.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 9-A1

TECHNOLOGY AREA: OPTICAL SYSTEMS (LOW LIGHT T.V. INSPECTION SYSTEMS)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Evaluate Current "State-Of-The-Art" (T.V. Systems) - Analyze Applicational Effectiveness - Comparatively Evaluate T.V. Systems vs Borescopes							
LONG RANGE ELEMENTS								
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: OPTICAL SYSTEMS

TASK NO. 9-A2 - BORESCOPE REFINEMENT

PROGRAM TASK DESCRIPTION:

The utilization of borescope techniques have made possible many, otherwise impossible, maintenance efficiencies. Further improvements in optical transmission efficiency for enhanced image resolution would be most desireable. This task would investigate optimum fiber shape, diameter, material and packing arrangements as they relate to inspection effectiveness.

APPROACH ELEMENTS:

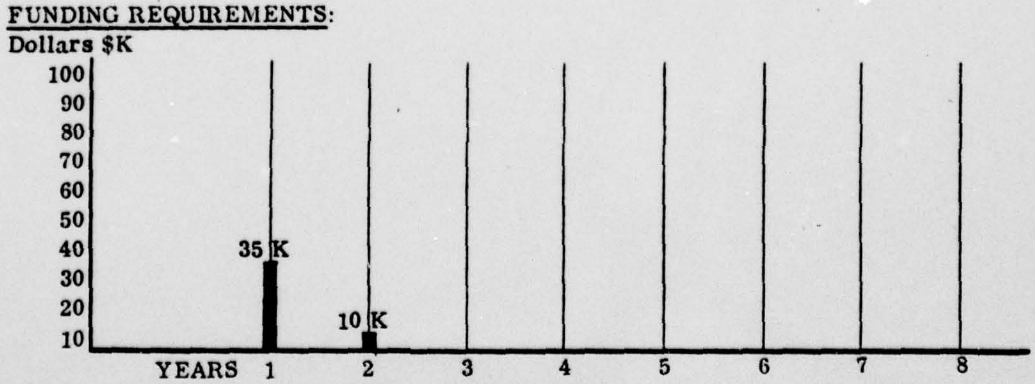
1. Investigate fiber optic image resolution factors.

2. Evaluate physical packaging options (rigid, flexible, zoom capability, stereo eyepiece, etc.)

3. Develop up-graded prototype borescope for field evaluation.

4. Conduct field evaluation.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 9-A2

TECHNOLOGY AREA: OPTICAL SYSTEMS (BORESCOPE REFINEMENT)

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Investigate Fiber Optic Image Resolution Factors - Evaluate Physical Packaging Options - Develop Prototype Scope For Field Evaluation							
LONG RANGE ELEMENTS		- Conduct Field Evaluation						
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: ACOUSTICAL HOLOGRAPHY

TASK NO. 10-A1

PROGRAM TASK DESCRIPTION:

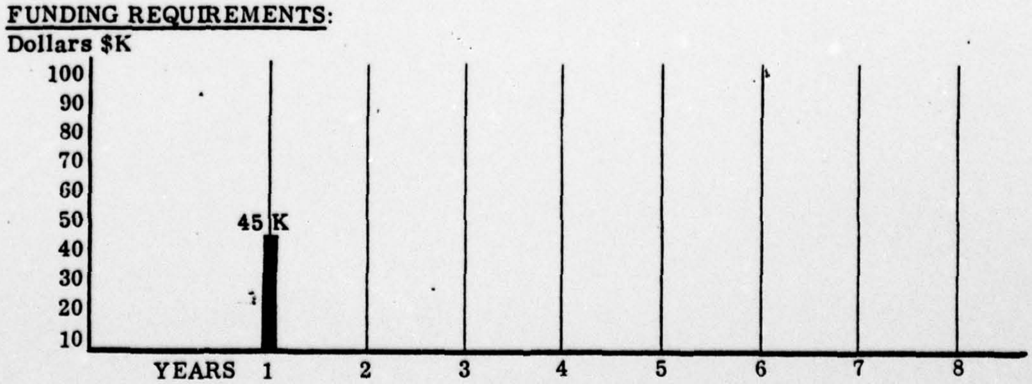
The development and application of acoustical holography inspection systems has progressed recently with respect to aircraft maintenance operations. Several recent demonstrations have indicated the value of acoustical holography, yet the high cost remains as a prohibitive factor. This task would investigate the potential of developing a low cost system for application to specific aircraft inspection requirements.

APPROACH ELEMENTS:

1. Conduct a study to establish viable alternatives to the present high cost acoustical holography system arrangements.

2. Evaluate the potential for reducing present acoustical holography system costs.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 10-A1

TECHNOLOGY AREA: ACOUSTICAL HOLOGRAPHY

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Investigate Low Cost Alternatives - Investigate System Cost Reduction Potentials							
LONG RANGE ELEMENTS								
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: OPTICAL HOLOGRAPHY

TASK NO: 11-A1

PROGRAM TASK DESCRIPTION:

Pulsed laser holography is a unique non-destructive evaluation concept which has been demonstrated in the laboratory for certain specific applications. What is now required is a more broadbased application analysis program to evaluate the usefulness in terms of scope of application. This task would investigate additional applications, regarding inspection methodology, and compare the results with current inspection methods.

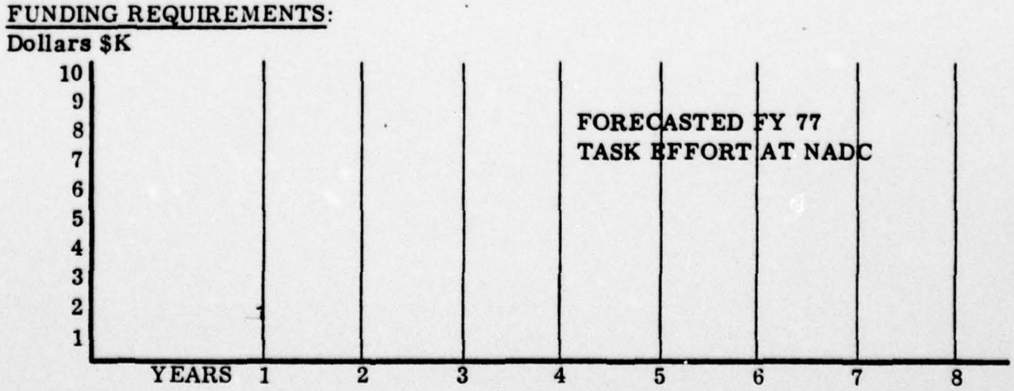
APPROACH ELEMENTS:

1. Generate a list of potential optical holography inspection candidates.

2. Conduct laboratory test program to evaluate inspection capability.

3. Comparative analysis of optical holography methods with alternative non-destructive evaluation techniques.

FUNDING REQUIREMENTS:



MILESTONE SUMMARY

TASK NO. 11-A1

TECHNOLOGY AREA: OPTICAL HOLOGRAPHY

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Generate Inspection Candidate List - Conduct Laboratory Test Program - Comparative Analysis of Alternative Methods							
LONG RANGE ELEMENTS								
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

TECHNOLOGY AREA: MECHANICAL IMPEDANCE

TASK NO. 12-A1

PROGRAM TASK DESCRIPTION:

One of the more recent techniques to find widespread applications in NDE is that of mechanical impedance or vibration measurement. This task would investigate mechanical impedance methods, the impact of advanced signal processing concepts for potential aircraft components and structural applications in order to establish the potential usefulness of this technique in the aviation maintenance environment.

APPROACH ELEMENTS:

1. Select critical aircraft component test specimens and analytically determine expected impedance response, flawed and unflawed.

2. Empirically determine via laboratory investigation the actual impedance response of flawed and unflawed test specimens.

3. Evaluate mechanical impedance methods with respect to inspection sensitivity and reliability.

FUNDING REQUIREMENTS:

Dollars $K

MILESTONE SUMMARY

TASK NO. 12-A1

TECHNOLOGY AREA: MECHANICAL IMPEDANCE

FISCAL YEAR

	n = 1	2	3	4	5	6	7	8
DEVELOP TECHNOLOGY BASE 6.2/6.3	- Select Critical A/C Component Test Specimen. - Analytically Determine Component Response -Empirically Determine Component Response - Evaluate System Effectiveness							
LONG RANGE ELEMENTS								
DEVELOP HARDWARE CAPABILITY 6.4/6.6								
SHORT RANGE ELEMENTS								

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NON-DESTRUCTIVE EVALUATION SYSTEMS FOR THE NAVAL AVIATION MAINT--ETC(U)
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C. SUMMARY OF RECOMMENDATIONS. This section summarizes the development recommendations for fleet NDE technology base development (6.2/6.3). Priorities are established which have been arrived at through an analysis of technology projections and operational requirements discussed in previous sectors. These priorities in conjunction with available funding for NDE related programs can be used to prescrive an NDE equipment development program.

TECHNOLOGY BASE DEVELOPMENT (6.2/6.3)	
PRIORITY	TASK NO.
1	1-A1
2	2-A1
3	5-A1, 5-A2
4	4-A1, 4-A1
5	1-A2, 2-A3, 3-A2, 7-A3, 6-A2
6	1-A3, 2-A2
7	12-A1
8	10-A1
9	9-A2
10	3-A1
11	7-A2
12	8-A1
13	7-A1
14	9-A1
15	11-A1
16	6-A1
17	8-A2

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16. Jacoby, J. L., Wright, J. E., "Feasibility Demonstration of Holographic Non-destructive Inspection of Naval Aircraft Engine Components", TRW Systems Group AT-3VD-TR-743, 27 March 1974.

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APPENDIX A. RECOMMENDED PARTICIPATING/SUPPORT ACTIVITIES.

1. NAVAL AIR ENGINEERING CENTER

   a. Equipment R&D Programs (6.2/6.3)
   b. Equipment Engineering & Procurement Programs (6.4/6.6)
   c. Engineering Test

2. NAVAL AIR DEVELOPMENT CENTER

   a. R&D Resource/R&D Program Support
   b. Future Inspection Requirement Inputs

3. NAVAL AIR REWORK FACILITIES (ALAMEDA, CHERRY POINT, JACKSONVILLE, NORFOLK, NORTH ISLAND, OCEANA, PENSACOLA)

   a. R&D Test Resource
   b. Engineering Test Resource
   c. Fleet Inspection Requirement Inputs

4. NAVAL AIR TEST CENTER

   a. Service Test

5. NDI SCHOOL (TRI-SERVICE) CHANUTE AFB

   a. Training Requirement Inputs
   b. Human Engineering Factors Inputs

APPENDIX B. PROPOSED ADVANCED DEVELOPMENT CONCEPT

A. NEW CAPABILITIES.

1. COMNAVAIRLANT in defining its ten foremost maintenance problems said: "While difficult to describe non-destructive t4st techniques as a problem, it is an area which promises great dividends, in our opinion, if properly exploited. As the personnel crunch gets tighter, we find ourselves often generating many of our daily problems by taking things apart and putting them back together incorrectly. Greater use of NDT could avoid at least some of this. We don't see from this distance a very vigorous program to take advantage of all available NDT procedures and we think such a program is worth strong pursuit. We have much to do at this level utilizing that equipment already available, but a companion development effort should be structured to provide us with all means available to avoid disassembly in order to inspect".

a. These comments by COMNAVAIRLANT are indicative of the trend in modern aircraft maintenance philosophy. Concepts of "progressive" and "on conditions" are becoming more prevalent. At the same time this evolution in maintenance practices has occurred, a significant expansion in NDE (non-destructive evaluation) technology base has also occurred. Such techniques as neutron radiography, ultrasonics, acoustic emission, thermography, holography, mechanical impedance methods, leak detectors, eddy-current devices, wear particle analysis and others have created numerous possibilities for improved diagnostics and aircraft system condition monitoring.

b. Commercial airlines have pioneered the application of a few of these techniques, and as a result, reaped generous savings in related aircraft maintenance costs.

c. The (1) requirement to reduce aviation maintenance support costs, (2) the availability of numerous advanced system diagnostic and evaluation techniques and the (3) current methodology of utilizing analytical approaches

in maintenance task planning has set the stage for a productive maintenance cost reduction program to be effected.

(1) The requirement to reduce aviation maintenance support costs. Maintenance manhours per flight hour has, over the years, moved steadily upward. Significant contributing factors are aircraft maintenance actions which involve much airframe disassembly and, in many cases, trial and error component replacement. This situation creates two modes of unnecessary resource depletion. The first is the expenditure of maintenance manhours to disassemble, inspect, and reassemble, when more powerful inspect only techniques could be applied. The second is the unwarranted burden placed on logistic resources to stock and refurbish components replaced by trial and error procedures, brought about via inadequate diagnostic capability.

As increased personnel and weapon system acquisition costs continue to pressure other military budget elements, the need to reduce system maintenance costs is apparent.

(2) The availability of advanced system diagnostic and evaluation techniques. Recently there has been impressive growth in many NDE (nondestructive evaluation) technology fields. A brief summary is given:

(a) Neutron Radiography - The advent of the man-made radioisotope Californium 252 (252 C_s neutron source) has made feasible on-site airframe inspection employing similar procedures as x-ray. Neutron radiography complements x-radiography because the relative absorption characteristics of most elements are essentially reversed. The neutron ray characteristics have proved advantageous for detecting airframe corrosion, composite material anomolies and entrapped water and hydrocarbons.

(b) Ultrasonics - Rapid expansion of ultrasonic signal processing and imaging techniques, spurred on largely by medical bioengineer-

ing research programs, offers the ability to probe within structures and components using high frequency sound waves. Utilization of ultrasonics in field applications has proved successful and extremely cost effective. The application of advanced ultrasonic inspection systems will expand further as more inspection possibilities are realized. (Air Force estimates an eighty (80) manhour savings for one particular aircraft component inspection alone.)

(c) Acoustic Emissions - This technique employs acoustic energy signatures of dynamic systems to evaluate system or component integrity. Advanced signal processing techniques and acoustic transducers have permitted monitoring of bearings, hydraulic systems, aerodynamic structures and active corrosion processes as well as other dynamic systems. The principle value of acoustic emission monitoring is that in most applications it provides early warning of system degradation.

(d) Thermography - The utilization of temperature gradients and differentials to detect system anomolies is the basic principle behind thermographic techniques. Temperature sensitive coatings, infrared cameras are the most common forms of thermographic testing. Applications include engine monitoring, aircraft structures, avionics and, in general, any component whose surface temperatures are functionally related to operational serviceability.

(e) Holography - This technical area has two aspects: (1) optical holography and (2) acoustical holography. Each utilizes coherent wave phenomenon to abstract component surface or interior anomolies. Holography has the ability to discern very small defects, on the order of crystal lattice dimensions. Holographic applications include tire evaluation, wing spar (A-6), and turbine blade crack detection.

(f) Mechanical Impedance - Airframe bond testing has been the most productive application of this phenomenon. The vibrational

response of structures to induced mechanical impulses is utilized to ascertain the structure's integrity. "Sonic" bond testers have been used to screen honeycomb laminants with significant reduction in inspection times.

(g) Wear Particle Analysis - Recent innovations in oil lubricated system diagnostics and condition monitoring has employed microscopic wear particle analysis in addition to spectrometric (element parts per million - PPM) oil analysis techniques to predict system failures. Particle size, shape, size distribution, along with specific information on expected wear modes, is utilized to diagnose system health. Applications include hydraulic systems, oil lubricated systems and grease lubricated systems.

(h) Eddy-current - Time varying electromagnetic field anomalies provide indications of surface or subsurface flaws in conducting materials and also to evaluate metallurgical conditions such as hardness and heat treatment. Eddy-current testing is used to good advantage over more established methods such as dye penetrant, and magnetic particle, by avoiding time consuming stripping and refinishing of components to be inspected.

(3) Analytical Maintenance Program Philosophy. The Navy's current optimization procedures for organizing aircraft maintenance support provides the ideal mechanism for capitolizing on improved NDE (non-destructive evaluation) techniques.

(a) As each aircraft type (A-4, A-6, F-4, etc.) maintenance program is formulated, particular attention can be focused to "on condition" maintenance requirements which could be handled more effectively with NDE (non-destructive evaluation). The identification of these potentials early in the aircraft's life cycle would enable long term cost savings to be realized. The key is in providing an interface for the maintenance program planners and the NDE (non-destructive evaluation) technical community to

join efforts. This program is being proposed to provide that essential interface, Figure 14.

B. TECHNICAL APPROACH.

1. The approach utilized would be to establish specific aircraft study groups, analyze maintenance actions for NDE applicability, assess NDE's role for technical feasibility, verify maintenance level capabilities and formulate implementation plan based on life cycle cost factors.

a. Study Groups. Select five candidate aircraft systems, one each for training, attack, fighter, patrol and heliocopter. Considerations for choosing a particular aircraft type would be availability of maintenance data and analytical maintenance program support.[1]

b. Maintenance Task Analysis. Analyze and categorize maintenance actions which would be potentially impacted by existing or improved NDE techniques. Figure 15 depicts the decision logic utilized in the Analytical Maintenance Program, designated (MSG-2). Specific attention would be focused on areas one (1) and two (2) as illustrated in Figure 15.

Area (1) - Expand the utilization of NDE for "on condition" system monitoring to improve the efficiency of inspection and test functions.

Area (2) - Application of NDE to accomplish "on condition" monitoring in areas not presently feasible.

c. Technology Assessment Phase. To validate proposed NDE applications, detailed investigations would be undertaken to establish feasibility within "stare of the art" constraints. Cross correlation of techniques vs requirements will provide optimal selection of candidate solutions.

d. Laboratory Investigations. Feasible candidates from the "Technology Assessment Phase" will be subjected to laboratory qualifications to guarantee validity. Exceptions would be those techniques which are common practice within the present aviation maintenance environment.

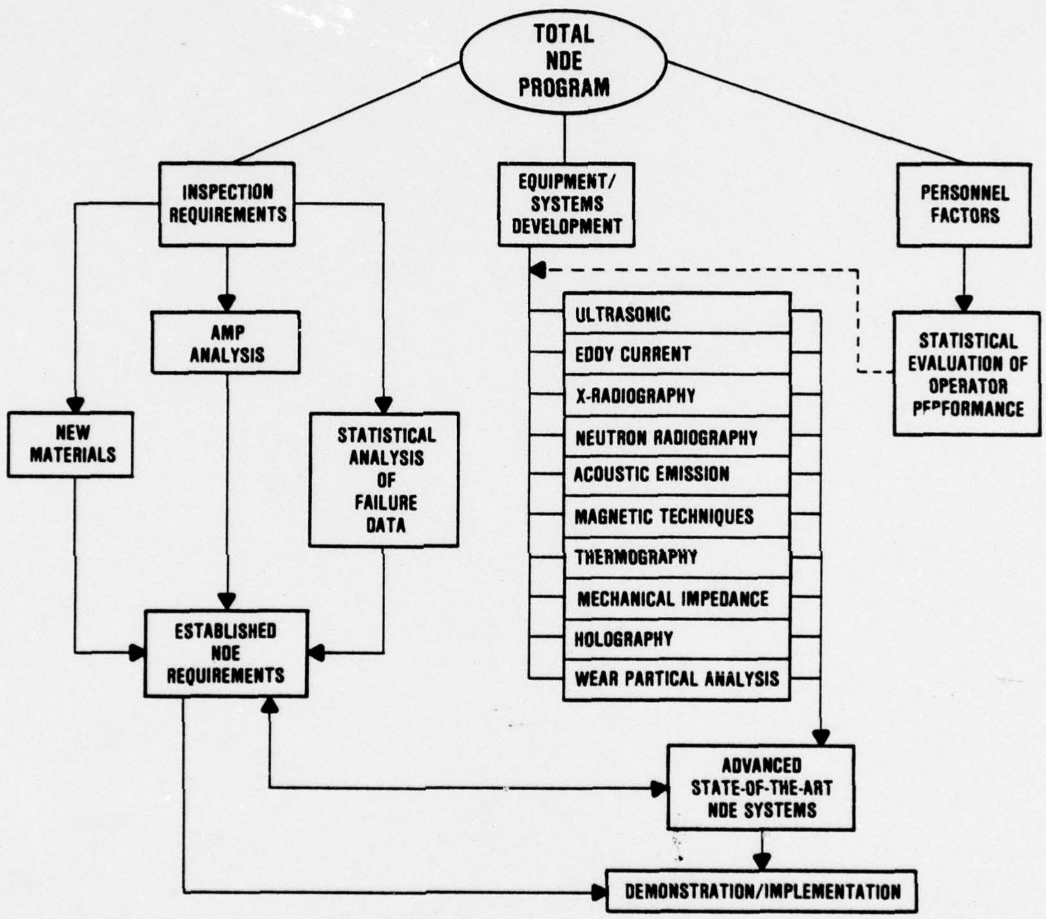

Figure B-1 NDE ANALYTICAL MAINTENANCE PROGRAM

ANALYTICAL MAINTENANCE PROGRAM/MSG-2 DECISION LOGIC

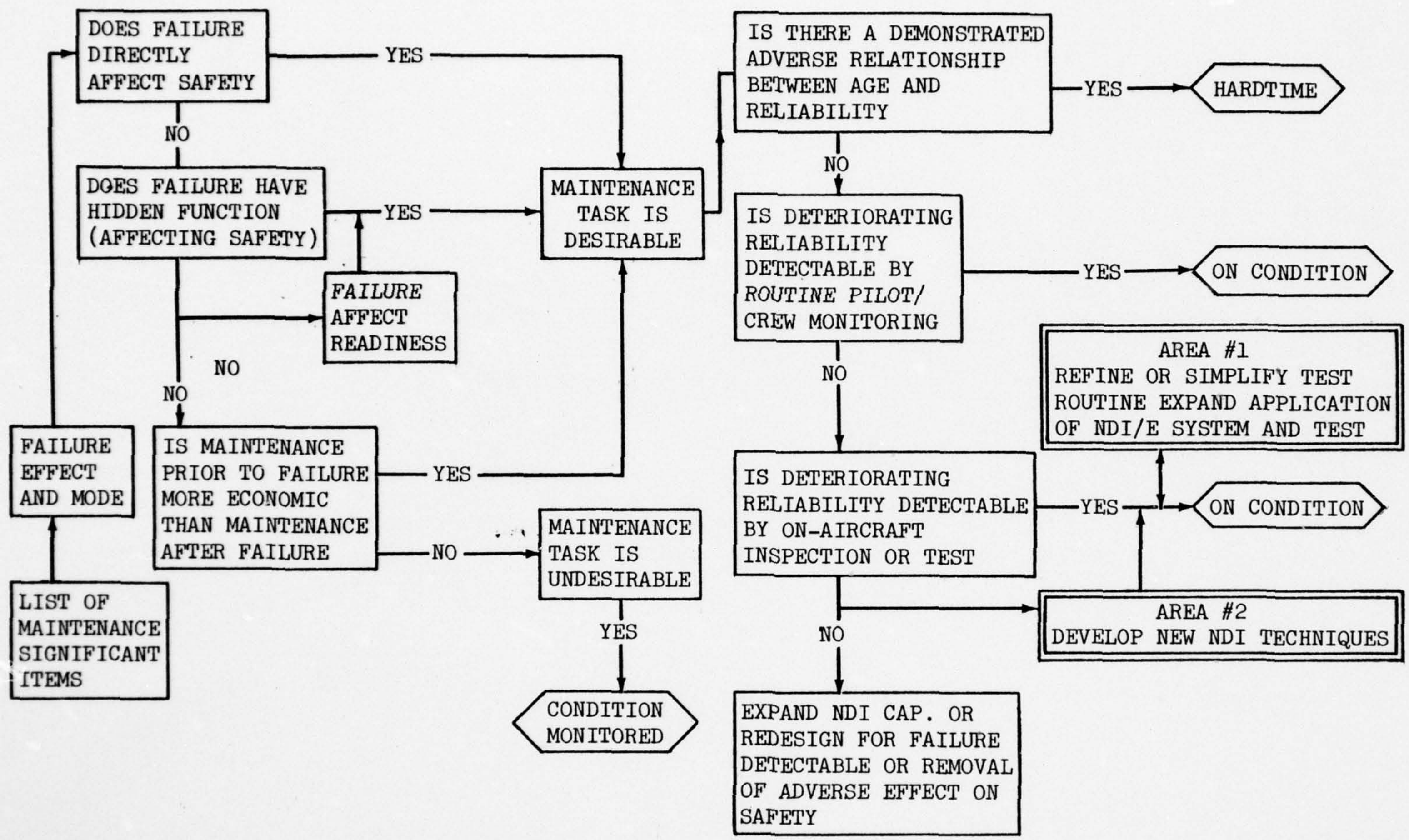

Figure B-2 ANALYTICAL MAINTENANCE PROGRAM ORIENTATION

e. Implementation Impact Analysis. Having determined feasible alternatives for the inspection and evaluation of naval aircraft systems, structures and components, an impact study would be conducted to determine the life cycle maintenance cost advantages to be balanced against other factors such as personnel training requirements, projected NDE equipment resources and other related factors. Payback periods would be calculated for various levels of investment in order to provide a definitive cost baseline for implementation planning.

C. OPERATIONAL EFFECTIVENESS.

1. Single cost savings or improved operational readiness figures are difficult to predict because of the large number of application possibilities available. However, a similar application program by the Air Force, applying only basic NDE techniques to the T-37 training aircraft yielded the following results:[2]

a. fifty (50) aircraft for one year/total accumulated flight hours - (58,000)

b. scheduled maintenance reduction in man/hours - 22%

c. unscheduled maintenance reduction in man/hours - 17%

d. inspection interval increase of 400 to 800 hours

e. total manhour savings - 200,000 hours

As more sophisticated and capable techniques are utilized and greater numbers of aircraft are covered by such innovative maintenance programs, the cost savings realized will become proportionally higher.

D. CRITICAL TECHNOLOGIES.

1. The expanded utilization of non-destructive evaluation concepts has already been proven in a number of aviation maintenance areas.

a. The technical risk involved is a statistical variable and is dependent on what particular NDE concept is being considered for application

The intent would be to expand application development rather than the state-of-the-art in any one specific technology area. Fields of high technical risk would be avoided in favor of more conservative alternatives when available.

APPENDIX C. FIRST DRAFT OF PROPOSED REVISION OF CHAPTER 712, NON-DESTRUCTIVE TESTING AND INSPECTION (NDT/I) PROGRAM OF OPNAVINST 4790.2A, NAVAL AVIATION MAINTENANCE PROGRAM.

712 NONDESTRUCTIVE TESTING AND INSPECTION (NDT/I PROGRAM)

a. Background. The increasingly complicated design of naval aircraft, coupled with decreased manpower and funding for maintenance, make it more imperative than ever that nondestructive testing and inspection be utilized for the early detection of structural weaknesses. The detection and correction of these faults before they reach catastrophic proportions can increase operational safety and readiness while dramatically decreasing maintenance man-hours.

b. Definition. NDT/I (Nondestructive Testing and Inspection) is the practice of evaluating a part or material without imparing its future usefulness. The methods used in naval aviation include, but are not limited to, visual or optical, dye penetrant, magnetic particle, eddy-current, ultrasonic, and radiographic.

c. Policy. To the maximum practicable extent, the full potential of NDT/I shall be explored and its capabilities employed in the maintenance of Navy and Marine Corps aircraft, aircraft systems and power plants wherever contributions to reliability, performance or economy can be realized.

d. Responsibilities. NDT/I is of vital concern at all levels of maintenance, and all operational and support commanders shall direct their efforts toward its proper prosecution. It is incumbent upon all military and civilian personnel to use initiative in exploiting NDT/I to the fullest practicable extent.

(1) NAVAIR is responsible for managing a program of research, development, and application of new NDT/I techniques and equipment, and for providing for the training of personnel in these techniques. NAVAIR shall:

(a) Coordinate and disseminate information on NDT/I within the naval aviation community, other services, and industry, as appropriate;

(b) Ensure appropriate application of NDT/I at all levels of maintenance;

(c) Procure NDT/I equipment for support of an effective program;

(d) Procure NDT/I manuals and technical publications and ensure the updating of such publications as the state-of-the-art progresses;

(e) Establish requirements for the application of NDT/I and include them in the MRC, MIMS or other appropriate publications;

(f) Establish necessary standards and specifications for NDT/I.

(2) NAVAIRSYSCOMREPs are responsible for:

(a) Providing NAVAIREWORK FAC support to intermediate and organizational level maintenance activities for the development of specific NDT/I procedures and applications;

(b) Providing NDT/I program guidance within the Depot, Intermediate and Organizational Level activities;

(c) Providing support for NDT/I training of military personnel at the NAVAIREWORKFACs when such training is requested.

(3) NAVAIREWORKFACs are responsible for:

(a) Fully utilizing available NDT/I equipment in the development of new, specific NDT/I procedures and applications to provide labor and material cost savings during inspection of all aircraft for which they have maintenance engineering responsibility/cognizance;

(b) Provide technical assistance (including limited on-the-job training and refresher training) on NDT/I matters to Intermediate and Organizational Level activities as directed by NAVAIRSYSCOMREPs;

(c) Ensuring that radiation monitoring (radiac) equipment is maintained and calibrated in accordance with NAVELEXINST 9673.9 series.

(4) TYCOMS are responsible for:

(a) Establishment of an NDT/I monitor for coordination and implementation of all NDT/I activities within their area of command;

(b) Distribution of NDT/I equipment to AIMDs/IMAs in accordance with the appropriate IMRL;

(c) Recertification of qualified NDT/I personnel;

(d) Assisting with updating of specifications, standards, manuals etc. that apply to Fleet use of NDT/I;

(e) Demonstration of updated techniques to AIMDs/IMAs within their area of command.

(5) AIMDs/IMAs are responsible for:

(a) Establishing, maintaining, and operating an NDI laboratory providing NDI services to Organizational level activities requiring such services on-site or otherwise;

(b) Establish positive control system for assignment and replacement of NEC coded personnel to NDT/I billets;

(c) Ensuring that NDT/I equipment authorized in activities' IMRL is on hand and in good working order;

(d) Ensuring compliance with Qualification and Certification requirements;

(e) Ensuring that NDT/I procedures are performed only by personnel qualified and certified to the necessary degree of proficiency;

(f) Ensuring compliance with all safety precautions;

(g) Ensuring that radiation monitoring (radiac) equipment is maintained and calibrated in accordance with NAVELEXINST 9673.9 series;

(h) Fully utilizing available NDT/I equipment and developing new NDT/I procedures which can substitute for more costly, time consuming DIR inspections; can implement anti-FOD programs following other maintenance operations; or can provide labor and material cost savings while increasing operational readiness and, safety and reliability.

(6) OMAs are responsible for:

(a) Requesting assistance of AIMD/IMA personnel when maintenance directives require use of X-ray, ultrasonic; eddy-current and magnetic particle equipment;

(b) Activities having NEC coded NDT/I personnel assigned shall make every effort to utilize these personnel in NDT/I billets. If possible, such personnel should be detailed to the supporting AIMD/IMA for utilization of their expertise and training as long as such detail does not interfere with the mission and readiness of the activity;

(c) Providing personnel to supporting AIMDs/IMAs to act as radiographers (or other) assistant when required for the performance of NDT/I;

(d) Obtaining on-the-job training for personnel required to perform emergency penetrant or magnetic particle inspections;

(e) Designating personnel from these latter categories as NDT/I trainees and selecting trainees to obtain more extensive NDT/I training.

(7) Specific Quality Assurance Responsibilities

(a) Monitor compliance with NDT/I qualification and certification requirements, safety precautions, and all applicable instructions, specifications and standards;

(b) Monitor the organizations NDT/I training program to ensure it is current and comprehensive;

(c) Monitor the application of NDT/I procedures to the maintenance of aircraft, during both on-condition inspection and when components are removed for inspection elsewhere. Special emphasis should be placed on those areas of NDT/I performed by trainee personnel not assigned an appropriate NEC code.

e. Methods. The following NDT/I methods are those most commonly used for the inspection of aircraft parts and materials. Their successful use depends heavily upon intelligent application in conformance with the appropriate guides, specifications and manuals, and very careful and discriminating interpretation of results.

(1) Visual or Optical Inspection - the oldest, simplest and most economical of NDT/I techniques. The human eye, with aids such as magnifiers, borescopes and microscopes is a very effective instrument for the detection and/or confirmation of surface cracks, pits etc. Many inspections, whether destructive or non-destructive, depend upon a visual assessment of the indication discerned by the earlier method.

(2) Dye Penetrant - an inspection method in which a highly penetrating liquid containing an easily discernible dye is permitted to flow into surface connected cracks/or other material discontinuities. After sufficient penetration time has been allowed, the excess penetrant is removed from the surface leaving behind penetrant which is retained within the material discontinuities. Application of a developer (either a dry fluffy material or a suspension of porous material) provides a capillary action which draws the excess penetrant to the surface providing a brilliant delineation of the anomaly. Presently, MIL-I-25135 recognizes two methods; the color contract dye penetrant system which usually uses a bright red dye against a white developer and is visible under white light; and the fluorescent penetrant method which utilizes a dye which fluoresces under "black light" (near ultraviolet wavelength) to provide a brilliant, easily seen indication against a purple background. Both systems are available with variations providing solvent removal, solvent or aqueous suspensions of developer, and other special variations.

(3) Magnetic Particle - a method used on ferromagnetic parts to find surface or shallow sub-surface defects. The defects interfere with the magnetic field set up in the material during testing and can be located by the accumulation of magnetic particles which cling to the material around these magnetic disturbances. Magnetic particles of various colors (red, white, gray, black) may be used dry, or in suspension in high purity kerosene for inspection under normal white light. A version of fluorescent particles is also available for use under "black light".

(4) Eddy-Current - during eddy-current inspection, a probe containing a coil through which an alternating current is passing is scanned over the surface of the material. Eddy-currents are electromagnetically generated within the part and instrumentation is available to detect cracks, and other material irregularities based on the changes in electrical resistance caused by such defects.

(5) Ultrasonic Inspection - during ultrasonic inspection, a burst of ultrahigh frequency sound is introduced into the test piece where it is converted into a low amplitude mechanical stresswave which travels through the material and is reflected off of internal flaws and cracks and other discontinuities. The amplitude and trans time of this reflected signal is displayed on a cathode ray tube in relation to signals from known reflectors within the part. Thus, a flaw may be detected and its relative size and location estimated.

(6) Radiography - during usual radiographic inspection, electromagnetic radiation known as X-rays pass through the part and onto a film producing a shadow image of the internal and external characteristics of the part. Further important information on Radiography is included in Paragraph 712i and its subparagraphs.

(7) Hardness Testing. This technique is based on the relationship between the hardness of a metal and its resistance to deformation. Both stationary and protable units are used. The stationary unit most commonly used in the Rockwell hardness tester while a commonly used protable hardness tester measures hardness on the Brinell scale.

(8) Other Methods. The state-of-the-art of NDT/I is expanding with additional types of equipment and physical disciplines. Some of these techniques are not suitable or economical for on-condition maintenance, but are suitable for production and laboratory use. These new methods will be introduced into naval aircraft maintenance when circumstances dictate. Some of these methods are infrared, thermal, acoustics; leak detectors, liquid crystals, thermal paints, holography and radioactive isotopes.

f. Application. The application of NDT/I shall be in accordance with NAVAIR 01-1A-16, Nondestructive Inspection Methods and the NDT/I sections of the specific structural repair manuals. The former manual is the general manual containing theory and general application data for the various NDT/I methods. The latter documents contain detailed inspection procedures for selected components of the particular aircraft. Some general areas where NDT/I has proven to be an invaluable maintenance tool are:

(1) Where internal defects cannot be discovered visually;

(2) Where excessive disassembly can be avoided;

(3) Where structural disassembly can be avoided;

(4) For quality assurance in the detection of substandard material or conditions;

(5) As an input for changes to, and to prove the validity of, periodic maintenance requirements.

g. Training. The Aircraft Maintenance Nondestructive Inspection Course, Class "C1" (C-603-3191), located at the Air Force Technical Training Center,

Chanute AFB, IL, provides comprehensive training in magnetic particle, color contrast and fluorescent dye penetrant, eddy-current, ultrasonic, and radiographic NDT/I methods. The curriculum provides instruction in both theory and practical application. Radiography is conducted under simulated flight line conditions. The training is available for both military and civil service personnel and information pertaining to quota requests, obligated service requirements, convening dates and medical examination is published in the Catalog of Navy Training Courses (CANTRAC) NAVEDTRA 10500.
Aviation Structural Mechanics, (S), Marine Corps MOS-6042, pay grade E-5 or above, and equivalent Civil Service personnel are eligible for this course. Special courses and refresher training can be provided by the NAVAIREWORK-FACs by arrangement with the NAVAIRSYSCOMREPs.

(1) The following documents contain information that is pertinent to the NDT/I Training Program:

(a) Catalog of Navy Training Courses, (CANTRAC), Vol. II, Part C, Air Interest Courses, NAVEDTRA 10500; Course No. C-603-3191.

(b) NAVAIR 01-1A- Qualification and Certification of Military NDT/I Personnel.

(c) NAVAIR 01-1A-16, Nondestructive Inspection Methods.

(d) NAVAIRINST 13070,1A of 22 Nov 1975; Assignment of Responsibility for NDT/I within the Naval Air Systems Command.

(e) COMNAVAIRLANTINST 4730.21 of 22 Apr 75; Establishment of Aircraft and Equipment NDT/I Program.

(f) NAVAIRSYSCOMREPACINST 1552.1 Series, Catalog of Specialized Training Courses for Military Personnel in Aviation Maintenance and Equipment Calibration.

(g) NAVELEXINST 9673.5 Series, Maintenance Responsibilities for Radiac Equipment.

(h) NAVELEXINST 9673.9 Series, Radiac Equipment Allowance of the Naval Shore Establishment.

(2) A Navy detachment has been established at Chanute AFB to provide administrative and instructor support for the NAVAIR NDT/I Training Program. Copies of correspondence and messages pertaining to NDT/I matters should be sent to this group to keep them aware of NDT/I happenings. The functional address is: Chief Petty Officer in Charge, Service School Command, Glakes, Detachment Chanute TWSMN, Chanute AFB, IL 61868, Atvn 862-3375/3380 (Msg. traffic - Chanute AFB, IL/TWSMN).

h. Qualification and Certification. Only persons qualified and certified in accordance with NAVAIR 01-1A- and the categories below shall perform NDT/I of naval aircraft.

(1) NDT/I Trainee - This category is the lowest skill level identified by an NEC no. in the NDT/I area. Any individual trained to perform only penetrant or magnetic particle inspection, or to act as a radiographer's assistant shall be identified as falling into this category. The training shall have been provided by NAVAIREWORKFAC or as OJT (on-the-job training) under a certified NDT/I Technician. Information pertaining to such training and utilization as an NDT/I Trainee shall be filed in the individual's training folder and such person shall be indicated as a candidate for training at the NDT/I School at Chanute AFB. Trainees shall be considered qualified only for the inspection technique for which they have been trained and only for the duration of an emergency period for which they have been trained.

(2) NDT/I Operator - Graduate of the NDT/I School of Chanute AFB with little or no practical experience. This individual shall be assigned an NEC number indicating that he should be allowed to perform NDT/I in conjunction with an NDT/I Technician and that he should not be assigned to any activity

where he would be the sole NDT/I category assigned. NDT/I operators shall have been qualified and certified, initially, upon successful completion of the NDT/I School and they must maintain their qualification by actual use of the test equipment. It is recommended that all NDT/I Operators initiate the practice of maintaining a personal NDT/I Performance Record showing aircraft, part number, inspection technique, date inspection performed and initials of the certified NDT/I Technician who witnessed the inspection. Such records should be maintained by all NDT/I personnel throughout their careers in the NDT/I area. Operators who have not used any of the NDT/I techniques, for which they were originally certified, for a period of 3 months shall requalify by OJT under a certified NDT/I Technician.

(3) NDT/I Technician - Graduate of NDT/I School with at least one year experience, as NDT/I Operator, during which NDT/I was performed for at least 75% of the working time. This individual should be capable of recommending acceptance or rejection of parts inspected and should also be capable of providing OJT to Trainees. Before an NDT/I Operator can be certified as an NDT/I Technician he shall have successfully completed a written examination administered by an NDT/I Senior Technician and shall also have demonstrated his inspection skills. NDT/I Technicians shall be recertified annually in accordance with NAVAIR 01-1A-

1. Radiography - Due to the nature of X-radiation and the hazards involved with its use, procedural safety precautions and qualification standards must be adhered to, as specified in this section. Designated activities with a certified aircraft radiographer assigned are authorized and directed to perform radiographic inspections on aircraft, power plants and aircraft accessories.

(1) Safety Precautions.

(a) The Maintenance Officer of an Intermediate Maintenance Activity provided with protable X-ray equipment is responsible to ensure that all radiographic operations are performed only by certified aircraft radiographers. The Maintenance Officer shall further ensure that each certified aircraft radiographer shall:

(1) Register with the local Radiological Health Officer.

(2) Obtain film badges from the Medical Department.

(3) Comply with all local regulations as well as those specified in the Radiological Health Protection Manual, NAVMED P5055.

(4) Comply with all safety regulations.

(b) Radiation monitoring equipment, preferably ionization chamber type radiac instruments, must be used to determine safe radiation areas. The AN/PDR-27, a Geiger type instrument with established maintenance, repair and calibration procedures, is an adequate monitoring device, but will indicate radiation levels slightly higher than they actually are. Use of the 0-5 mr/hr scale is recommended for setting the 2 mr/hr limit.

(c) All radiographic operations shall be performed within a RESTRICTED radiac monitored, roped-off area, to ensure that personnel are not subjected to a radiation dosage exceeding 2 mr/hr. The roped-off area shall be identified with appropriate radiation warning signs and will be under continuous surveillance by the aircraft radiographer and his authorized assistants. The aircraft radiographer and his authorized assistants shall be instructed to recognize hazards and to observe safety regulations, and shall be registered with the radiological Health Officer.

(d) Whenever possible, shipboard radiography shall be performed on the flight deck with the X-ray beam directed outboard. At no time may the X-ray beam be directed toward the island. The X-ray beam may be directed toward the deck in flight deck operation, since the deck thickness provides

adequate protection for personnel below. Hangar deck radiography, when required can be performed safely with strict adherence to the precautions prescribed in sub-paragraph 7121(1)(c). The area in which the radiography is to be performed must be secured and isolated. Certified radiographers and/or authorized assistants shall ensure that no other personnel are present in a hazardous area during radiographic operations. If possible, hangar deck operations should be performed in the immediate vicinity of an elevator, with the X-ray beam directed outboard. Lead shielding shall be used in shipboard operations to protect personnel from possible secondary radiation.

(2) Equipment - Related Items.

(a) Industrial Radiographic X-ray Apparatus, Portable.

(1) X-ray unit, P/N 65B279 (78446)

(2) X-ray unit, P/N E326 (04322) or P/N 30102 (04322). The units, equally serviceable, are delicate electronic devices which require careful handling. Intermediate maintenance activities which have a certified radiographer assigned are authorized to requisition X-ray unit(s) in accordance with their IMRL (Individual Material Readiness List). For initial issue, a MILSTRIP requisition should be submitted by message or speedletter to the Commanding Officer, ASO Philadelphia, with info copies to Supply Officer, Naval Air Station, Jacksonville, and Commanding Officer, NAVAIREWORKFAC Jacksonville (534), noting the name, rate/rank, serial number and applicable NEC (AM-7225)/MOS (6044) of the radiographer assigned.

(b) X-ray Film Illuninator, P/N 46-122561G1 (24446) or P/N 46-122561G (24456) should be requisitioned through normal supply channels.

(c) A Kit of Related Components, P/N E50-6182-1 (96547) or P/N E50-6182-1 (25664), should be requisitioned through normal supply channels, with info copies as noted in paragraph (a) above. This kit consists of three

14 inch x 17 inch and six 8 inch x 10 inch cassettes, six 14 inch x 17 inch and six 8 inch x 10 inch lead screens, three sets of lead numbers, three sets of lead letters, aluminum and steel penetrameters, three warning signs, and a packing list with the information necessary for reordering consumbable items.

(d) The following radia equipment is required:

QTY	NOMEMCLATURE	P/A
12	Dosimeter-0-200-MR	IM-9/PD
2	Dosimeter Charger	PP-4276/PD or PP-354/PD
2	Survey Meter	AN/PDR-27

NOTE

Action has been initiated to provide an ionization chamber type instrument, such as a Victoreen Model 440 Survey Meter, in lieu of the An/PDR-27. Until the replacement item becomes available, the AN/PDR-27 will be furnished. Monitor devices should be obtained through the Station Radiological Control Officer. A letter of request for monitor devices should be submitted via the cognizant Radiac Co-ordinator, as indicated in NAVELEXINST 9673.5 series and via the chain of command, to the Commander, Naval Electronic Systems Command (Code 0516). The equipment will be provided without any further action by the requesting activity. NAVELEXINST 9673.9 series covers the administration of the radiac equipment allowances program.

(e) Protoective vinyl or rubber-leaded screens mounted on steel brackets with casters are available in 1/8-inch-thick lead, 4 feet wide x 7 feet high. Lead Sheet is also available in 1/i-inch thickness, 24 inches wide, from companies such as the KELEKET Division of Laboratories for Electronics, Incorp., 1601 Trapeco Road, Waltham, Mass. Order through open purchase. On shipboard, use of lead screens is required.

(f) Facilities obtaining portable radiographic equipment should utilize the darkroom facilities of the Medical Department, if a suitable darkroom is not available in the AIMD. A simple darkroom can be constructed at a relatively low cost; the recommended size darkroom is 6 feet x 8 inches. Several plans for darkroom construction (NAS Jacksonville drawings; E59-0020 and E59-0021) may be furnished upon request to NAVAIREWORKFAC Jacksonville.

(3) X-ray Unit Repair

(a) Intermediate level Maintenance Repair. Periodic inspection and maintenance of X-ray units should be accomplished in accordance with the Handbook of Operations and Service Instruction applicable to the unit assigned. Normal repair of the X-ray controller assembly is considered to be within the capabilities of the IMA, by using the Handbook of Operations and Service Instruction. Publications pertinent to the items employed are listed as follows:

(1) NAVWEPS 19-5-25-X-ray film illuminator.

(2) NAVWEPS 19-1-85-x-ray apparatus, radiographic, industrial (Sperry) operator/service instructions, W/IPB.

(b) For repairs not considered within the capabilities of the AIMD, the complete unit (controller assembly, tubehead and all components) should be shipped to the Naval Air Rework Facility (Materials Planning Division), NAS Jacksonville, Florida. Pack in accordance with paragraph 3-14 of

NAVWEPS 17-15-21.

(c) A brief description of the malfunction should be provided with the unit in the controller assembly or tubehead case. A message request for repair or exchange should be submitted to NAVAIREWORKFAC Jacksonville, with information copy to NAVAIRSYSCOMREPLANT, advising serial number of inoperative unit, urgency of requirement and the transportation priority assigned. The name, rate/rank, serial number and applicable NEC (AM-7225) or MOS (6044) of the radiographer assigned should also be noted.

(d) A pool of RFI X-ray units is maintained at NAVAIREWORKFAC Jacksonville, Florida. Exchange units will be provided upon receipt of the message mentioned above.

(e) Maintenance, repair and calibration of Radiac equipment is specified in NAVELEXINST 9673.5 series. Problems regarding operation, reliability, repair, maintenance or calibration of radiac equipment should be submitted to the Cognizant Radiac Coordinator, as listed in NAVELEXINST 9673.9 series.

FIGURE 11-2-1 REVISE AS FOLLOWS

FUNCTION	LEVEL		
	Dep.	Int.	Org.
Examination and Testing			
Magnetic Particle Method			
Installed equipment	X1,2	X1,2	
Portable equipment	X1,2	X1,2	X2,4
Dye Penetrant Method			
Fluorescent	X1,2	X1,2	X2
Color Contrast (not recommended for repetitive insps.)	X1,2	X1,2	X2
Eddy Current Method	X1,2	X1,2	X2,4
Ultrasonic Method	X1,2	X1,2	X2,4
X-Ray Method	X1,2	X1,2	X2,4
Magnetic Leakage Field Method	X1,2	X1,2	X2,4
Magnetic Perturbation Method	X1,2		
Hardness Test Method			
Installed Equipment	X1	X	X
Portable Equipment	X1	X	X4

X. LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AE - Acoustical Emission
AIMD - Aircraft Intermediate Maintenance Department
ASO - Aviation Supply Office
CFA - Cognizant Field Activity
COMNAVAIRLANT - Commander Naval Air Force Atlantic
CRT - Cathode Ray Tube
DOD - Department of Defense
FOD - Foreign Object Damage
Hz - Hertz
I Level - Intermediate Level
IMA - Intermediate Maintenance Activity
IR - Infra-red
KHZ - Kilohertz
KR-85 - Krypton Gas
MHZ - Millihertz
MOS - Military Occupational Speciality
MRC - Maintenance Requirement Card
NAMP - Naval Air Maintenance Program
NARF - (NAVAIREWORKFAC) Naval Air Rework Facility
NAS - Naval Air Station
NAVAIRSYSCOM - (NAVAIR) Naval Air Systems Command
NAVAIRSYSCOMREP - Naval Air Systems Command Representative
NAVELEXINST - Naval Electronics Command Instruction
NDE - Non-Destructive Evaluation
NDI - Non-Destructive Inspection
NEC - Naval Enlisted Classification
OJT - On The Job Training
O Level - Organizational Level
R&D - Research and Development
RF - Radio Frequency (Energy)
RFI - Ready For Issue
TYCOM - Type Commander
UR - Unsatisfactory Report
X-Ray - X-Radiography

DISTRIBUTION LIST

NAVAIRSYSCOM AIR-5203 (2)
NAVAIRSYSCOM AIR-0340E (4)
NAVAIRSYSCOM AIR-5343 (2)
NAVAIRSYSCOM AIR-411 (2)
NAVAIRDEVCEN 60633 (3)
COMNAVAIRLANT 528 (2)
COMNAVAIRPAC 75 (2)
NAVAIRTESTCEN SY-54 (2)

NAEC:

92713 (1)
92724 (15)
92A12 (2)
92A1 (1)
1115 (1)
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REVISION LIST

REVISION	PAGES AFFECTED	DATE OF REVISION